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FINAL REPORT

Parametric Analysis of RF Communications and Tracking Systems for Manned Space Stations

NASA Contract NAS 9-12010

HUGHES

HUGHES AIRCRAFT COMPANY
SPACE AND COMMUNICATIONS GROUP

Hughes Ref. No. C4663 SCG 20588R

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Prepared by
Hughes Aircraft Company
Space and Communications Group
for
Manned Spacecraft Center
Houston, Texas

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Volume I

VOLUME I

SYSTEM ANALYSIS AND BASELINE DESIGN

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CONTENTS

1. INTRODUCTION

This document is the final report of the Parametric Analyses of RF Communications and Tracking Systems study conducted by the Hughes Aircraft Company, Space and Communications Group for the National Aeronautics and Space Administration, Manned Spacecraft Center. This work was performed under Contract NAS 9-12010.

The objective of the study was to analyze and evaluate system performance, system interface compatibility, and system management and operations of the external and internal communications provided by the modular space station (MSS). The MSS baseline design for these analyses was developed by NAR, Space Division under Contract NAS 9-10409.

The first task involved constructing the mathematical models and calculating the performance of the various external communication links between the MSS and the tracking and data relay satellite (TDRS), the shuttle, and the ground stations. In parallel with this, the communication control design requirements were determined from the overall MSS control design and philosophy of the NAR baseline and self-test and checkout requirements developed by McDonnell Douglas Astronautics Company on a related system study. These analyses are presented in Section 3.

Based on these requirements, two parallel design efforts were conducted to synthesize appropriate equipment configurations for the external communication assembly (ECA) baseband equipment and the internal communication assembly (ICA) equipment to accommodate the communication signal transfer and control. A major design consideration in the ECA task was the control system design and related communication equipment arrangement. These design trades are discussed in Section 4.

The trade considerations for the ICA centered about the use and design of the audio-video bus and its interfaces with the ICA audio and video equipment. These studies (presented in Section 5) recommended a flexible FDM bus design with standardized interfaces and integral control facilities.

The recommended baseline design which resulted from these studies is described in Section 2. In this design, particular emphasis was placed on defining the interfaces between equipment groups and the critical functional and signal characteristics at these interfaces. This information is contained in the performance and interface specification which is included as Volume II of this report.

2. BASELINE DESIGN

The modular space station communication equipment includes all those facilities for transmission and reception of a variety of data between the ground, the tracking and data relay satellite (TDRS) and the shuttle. It also includes the facilities for voice and video internal communications and comprehensive command and monitoring of all communication facilities under the control of the data processing assembly (DPA).

For this study, these equipments have been arranged in two groups, the internal communication assembly (ICA) and the external communication assembly (ECA), each with its own control facility (Figure 2-1). The DPA has direct communication circuits to the ECA for the transmission and reception of data, and the control interface is provided via the digital data bus and a remote acquisition and control unit (RACU). The ICA communication circuits interface with the ECA by means of the audio video bus and audio video units (AVUs). The ICA also has a control interface with the DPA through a RACU.

Shown in Figure 2-1 is the equipment for one station module. A complete set is provided in both the SM-1 and the SM-4 shown in Figure 2-2, which gives the physical arrangement of communication equipment for the complete MSS.

The following sections describe the external and internal communication assembly designs.

2.1 EXTERNAL COMMUNICATION ASSEMBLY

This section describes the design and operation of the external communication assembly. The signal paths are traced for representative communication modes for each of the RF links and typical command and monitoring operations are described.

2.1.1 Group Identification

The external communication assembly is comprised of eight groups as shown in Figure 2-3:

1) S band group

2) K band group

3) Carrier modem group

4) Subcarrier modem group

5) TDM group

6) Delta modem group

7) Baseband switching group

8) Control group

The S and K band groups include all transmitter and receiver equipment to support the RF links from the IF through the antennas and diplexers. The S band group also includes the transmit and receive RF switches to connect selected antennas with selected modulator/demodulator circuits and with the ranging equipment. Similarly, the tracking receivers and antenna control equipment to autotrack K band TDRS signals are included with the K band group.

These two groups were designed by NAR/ITT on previous studies (Reference 1) and will not be further described here. The equipment arrangement in the remaining groups was defined during this study and is described in the following sections.

2.1.2 K Band TDRS Links

K band TDRS links are the primary communication links between the MSS and the ground. The equipment operation to support these links is best shown by tracing the signal paths for typical modes. A typical configuration for the MSS to ground direction is comprised of three voice channels and 5 Mbps experiments data (link I, mode 4, Tables 4-1 and 4-3).

Referring to the ECA detailed block diagram, Figure 2-3, the voice signals enter the ECA from the audio video bus and the audio video unit that provides three parallel, 4 kHz voice channels. The three voice channels are individually connected by baseband switch A to three selected delta modulators. The outputs of these modulators, at 19.2 kbps each, are connected by baseband switch B to a low rate digital multiplexer and biphase modulator combination where they are combined into a nominal 60 kbps serial stream and modulated onto a 9.045 MHz subcarrier.

The 5 Mbps experiments data signal enters the ECA through baseband switch B which connects it to one of two subcarrier quadriphase modulators at 2.275 MHz. The quadriphase and biphase subcarrier modulator outputs are connected to channels 1 and 3, respectively, of a selected frequency modulator by baseband switch C and the channel gain controls are set by command for the proper modulation index for each signal. The IF output from the frequency modulator feeds an upconverter which provides an S band modulated carrier to the RF transmit switch from which it is routed to a selected amplifier and K band antenna.

To illustrate how the ECA can be reconfigured for different modes, consider a change to mode 6 that combines three voice channels, a 0.5 MHz facsimile signal, and a composite color television signal on one K band carrier. The voice channels would remain as they were established for mode 4 and the quadriphase subcarrier modulator would be deleted. The analog facsimile signal that enters the ECA through baseband switch A is connected to one of two linear subcarrier frequency modulators (commanded to 6.415 MHz) and terminated on baseband switch C. The composite television signal from the audio-video unit is connected directly to baseband switch C. The television video and the facsimile subcarrier signals are then connected to channels 1 and 2, respectively, of the frequency modulator. The modulation indexes for channels 1 and 2 are set by commanding the frequency modulator gain controls and mode 6 is established.

A third example of the MSS to ground K band link is an all-TDM mode (No. 8) which time-division-multiplexes three voice channels, a 500 kbps systems data channel, and a 5 Mbps experiments data channel into a composite 6 Mbps (nominal) channel. The voice channels enter the ECA and are delta-modulated as previously described. Baseband switch B applies the three delta modulator outputs and the systems data and experiments data inputs to the five parallel inputs of a high rate digital multiplexer. The output of this multiplexer is a 6 Mbps formatted composite of the voice, systems data, and experiments data which is applied to a channel encoder. The channel encoder is a constraint length 7, rate one-half convolutional encoder which outputs 12 Mbps to a carrier quadriphase modulator and upconverter.

For the forward link (ground to MSS), mode 5 is a good example as it contains three digital voice channels and a PCM entertainment signal multiplexed into subcarrier channel 2 and multiplexed control and computer data in channel 1. This carrier proceeds from the K band antenna and receive electronics through the receiver RF switch at S band to two downconverters that are tuned to its S band frequency by command. One of these downconverters is connected to one of two tracking receivers where the antenna pointing information is demodulated.

The other downconverter is connected to one of three frequency demodulator inputs. This demodulator has received control commands that establish the carrier acquisition search range and rate. When the carrier is acquired, the subcarrier signals are available at the demodulator's outputs that are terminated at baseband switch D.

Each of the subcarrier signals is connected to one of the six biphase demodulators whose input frequencies have been commanded appropriately (500 kHz for channel 1 and 1.45 MHz for channel 2). These demodulators have also been configured to search for a 510 kbps rate in channel 1 and 200 kbps in channel 2. The subcarrier demodulators provide parallel data and bit timing (clock) signals to the digital demultiplexers connected to their outputs.

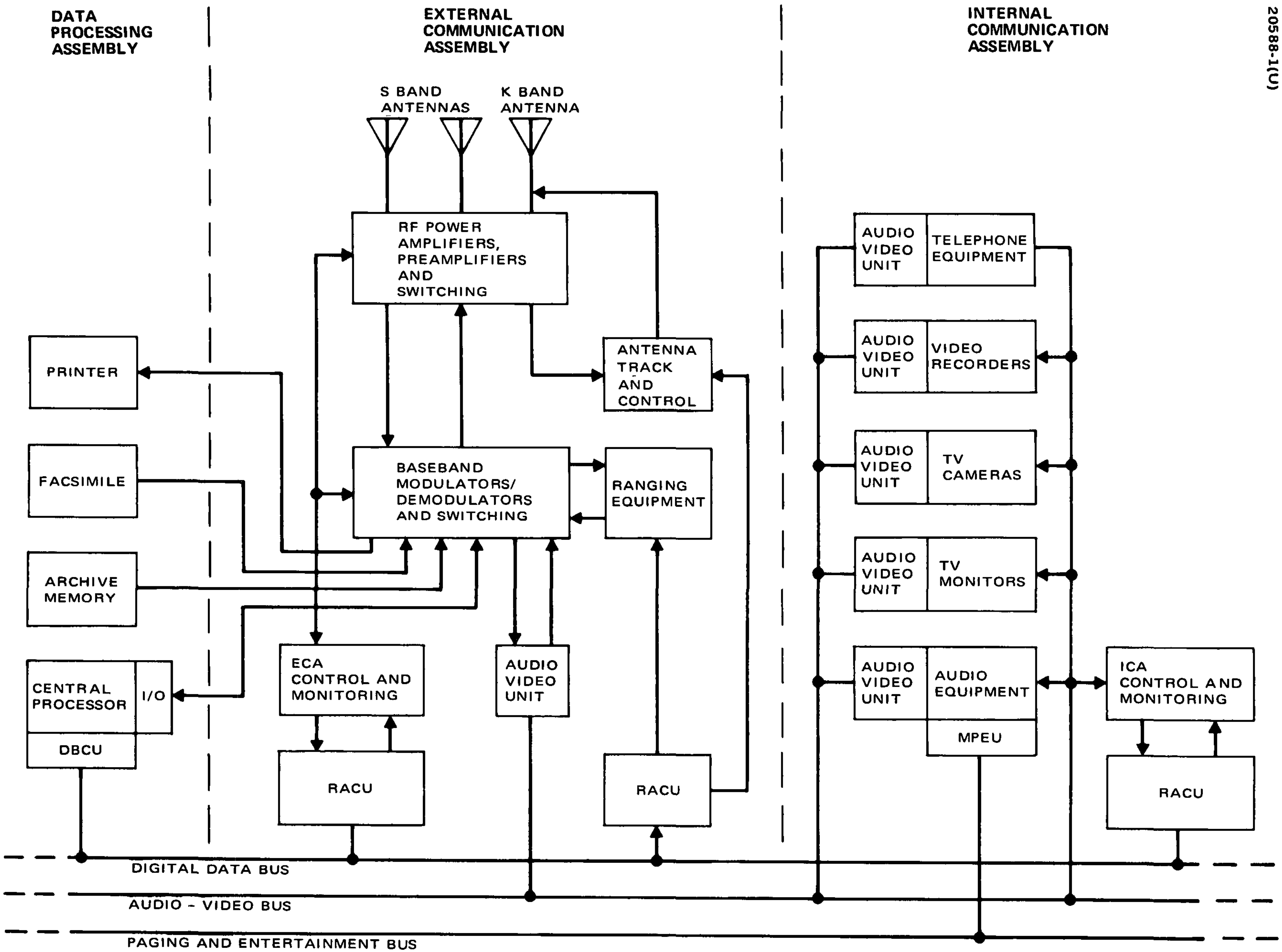

Figure 2-1. SM-1 and SM-4 Communication Equipment

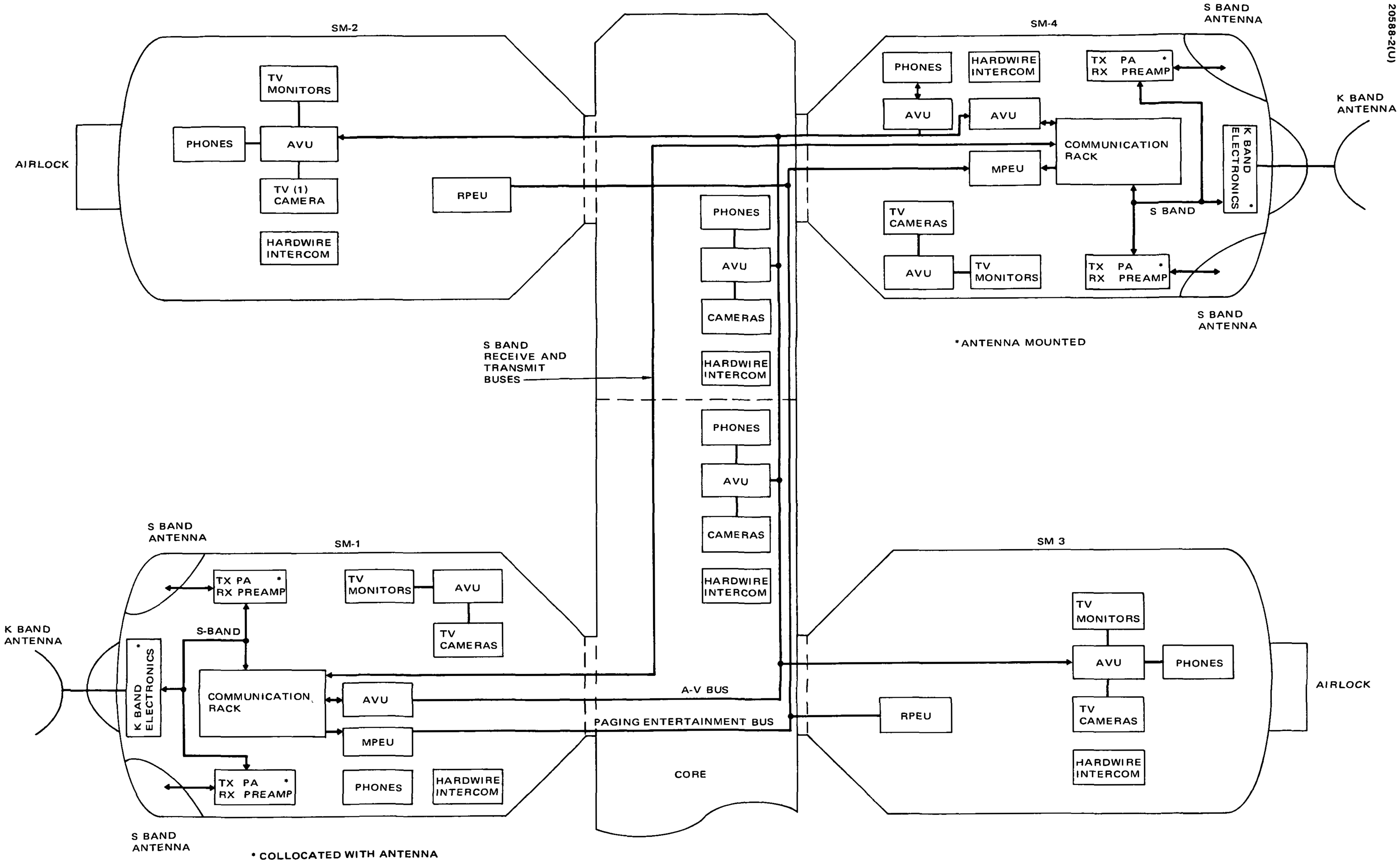

Figure 2-2. MSS Communication Assemblies Physical Arrangement

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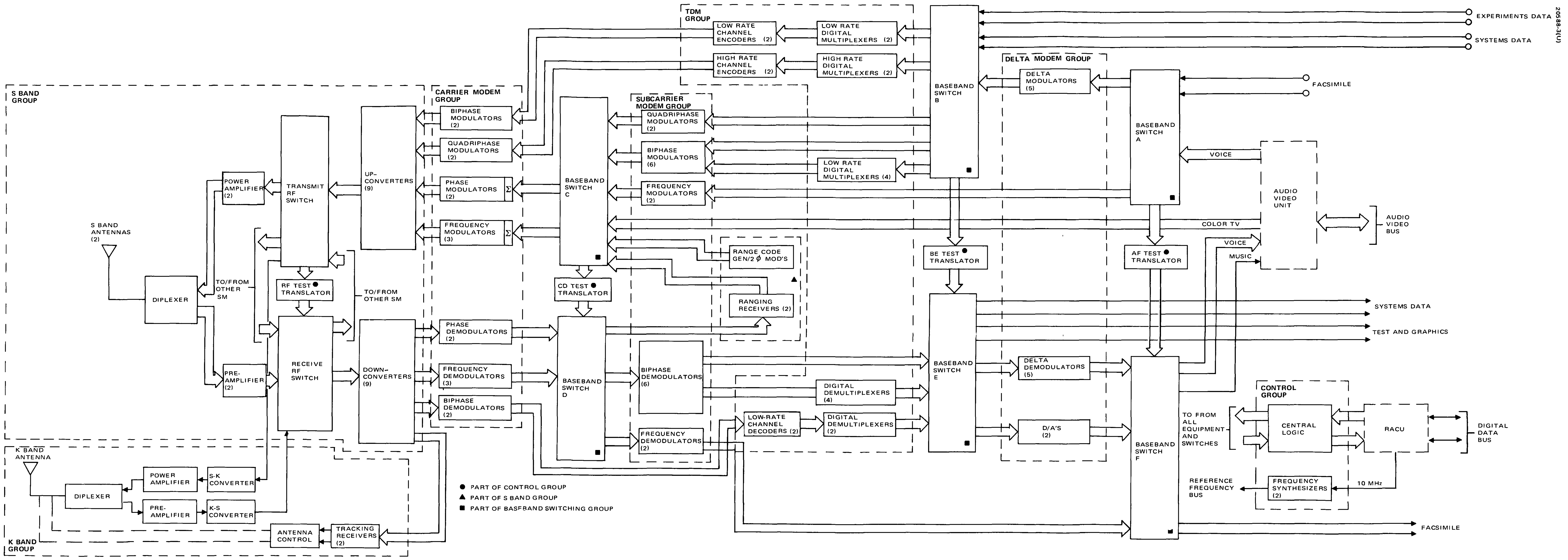

Figure 2-3. ECA Block Diagram

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These demultiplexers have also received commands that inform them of the multiplex format at their input and the number of parallel, serial outputs required. These outputs are connected to baseband switch E, which connects the control and computer data signals to parallel systems data circuits to the DPA. It also connects the three parallel digital voice signals and the digital entertainment signal to three of five delta demodulators and one of two digital-to-analog converters, respectively. These analog outputs (three voice and one 10kHz audio) then connect to the AVU for transmission to the ICA via baseband switch F.

This mode would be converted to mode 3 by the substitution of facsimile in channel 1 for the control and computer data. In this instance, the channel 1 output of the carrier frequency demodulator connected at baseband switch D would be routed to one of two frequency demodulators in the subcarrier modem group. The analog output of this demodulator goes directly to baseband switch F where it is connected to facsimile output circuits to the DPA.

When a text and graphics signal is sent over channel 1 (mode 4), it is connected to a biphase demodulator as was done for mode 5, but as it does not require demultiplexing, the signal goes directly to an assigned circuit to the DPA via baseband switch E.

For all the digital circuits, bit timing is carried forward in parallel with the data from the output of the subcarrier biphase demodulator when bit synchronization is acquired from the incoming subcarrier. This is not necessary for the analog signals provided on single output circuits.

2.1.3 S Band TDRS Links

Single mode, duplex links via the TDRS at S band are provided as a backup to the K band links. The reverse link (from the MSS to the ground) carries a single digital voice channel and 50 kbps of system data; one digital voice channel and 10 kbps of control data are provided in the forward direction.

As these are specially configured emergency circuits, they employ mostly dedicated (nonswitched) equipment. In the transmit side, switching selects one of five voice delta modulators and connects the output and the appropriate system data line from the DPA to one of two available sets of low rate multiplexers, channel encoders, carrier modulators, and upconverters. The output of the upconverter is then switched to the selected S band power amplifier and antenna.

This arrangement is mirrored on the receive side where the incoming signal is switched to one of two downconverters, each of which is connected to a biphase demodulator, channel decoder and digital demultiplexer combination. The outputs of the demultiplexer are then switched to a systems data line to the DPA and a voice delta demodulator and then to the ICA.

2.1.4 S Band Ground Links

The S band ground links provide signals identical to the K band TDRS FDM modes (link I, No. 1-7 and link II, No. 1-5). These are configured in an identical manner to the K band links, except the S band carriers are connected to S band amplifiers and antennas. In addition to these signals, there are some additional modes with turnaround ranging that will be described here.

In the forward direction (link VI), there is a ranging signal and three multiplexed voice channels plus text and graphics (mode 1), control data (mode 2), or computer data (mode 3). The received carrier is converted to one of two downconverter/linear phase demodulator combinations by the receive RF switch. This demodulator has received carrier acquisition range and rate instructions as is done for the frequency demodulator described in the K band link.

The output of channel 1 is switched by switch D to the ranging receivers of the S band group. The outputs of channels 2 and 3 are connected to biphase subcarrier demodulators from where they proceed as in earlier examples to provide three parallel voice channels to the AVU and the control or computer data on the systems data line to the DPA or text and graphics on its DPA circuit.

In the reverse direction (link V), mode 3 is the best example as it includes all the possible signals: the return ranging signal, three multiplexed voice channels, and 50 kbps systems data.

The voice signals are encoded and multiplexed as in previous examples and this 60 kbps bit stream and the systems data input from the DPA are connected to two of six biphase subcarrier modulators.

The biphase modulators have their output frequencies commanded to 1.995 and 2.690 MHz for voice and systems data signals, respectively. These modulated subcarriers and the ranging signal to be returned from the ranging receiver are connected to the three input channels of one of two linear phase modulators in the carrier modem group by baseband switch C.

The modulation index for each of the three channels is set by channel gain commands received by the phase modulator. The output of the modulator is then connected to a selected S band amplifier and antenna in the usual manner.

2.1.5 S Band Shuttle Links

The S band shuttle links (links VII and VIII) are constructed similarly to the previous K band TDRS links as FDM-FM carrier modulation is used. There is no unusual arrangement of the equipment for these links, but the operation is different because the full signal requirements are not provided at maximum range, but are added as the range is reduced between the shuttle and the MSS.

The baseband is arranged in the order the services are provided (Figure 4-3). The first service established is a 10 kbps low rate data channel, next is a multiplexed single-channel voice and medium rate (50 kbps) data channel, and then the ranging signal is added.

To receive these signals, it is necessary for the frequency demodulator's loop bandwidth to be adjusted as new subcarrier channels are added. An alternative implementation would be to provide three separate demodulators connected in parallel at the downconverter output with their characteristics tailored to the three different information bandwidths (15 kHz, 125 kHz, and 1.662 MHz).

2.1.6 Control Group Design

The control group includes those equipments necessary for operation and test of the external communication assembly: control and monitoring circuitry to accept and execute DPA commands and report the performance of the communication equipment, and special test facilities and reference signal generators.

Control and Monitoring Equipment Operation

The external communication assembly (ECA) and the internal communication assembly (ICA) of the modular space station are controlled by their respective control groups, which in turn are controlled by the data processing assembly (DPA). The control and monitoring equipment of the ECA and ICA each consists of a control group central unit, a multiplex data bus, and up to 16 remote multiplexer/demultiplexer units (see Figure 2-4). The central unit and the remote multiplexer/demultiplexer units are identical in the ECA and the ICA, except that the number of multiplexer/demultiplexer inputs and outputs and the programs in the central units are suited to the requirements of each application. The functions of the control and monitoring equipment include:

1) Remembering the operational status of the communication equipment to be used in the communication groups and choosing the specific items of equipment to be used in establishing communication paths within the communication assembly

2) Generation of commands to control the communication equipment and circuit switches of the ECA or the ICA

3) Generation of test signals in response to commands from the DPA

4) Sampling and conditioning of analog and bilevel discrete signals, and transmission of their values to the DPA

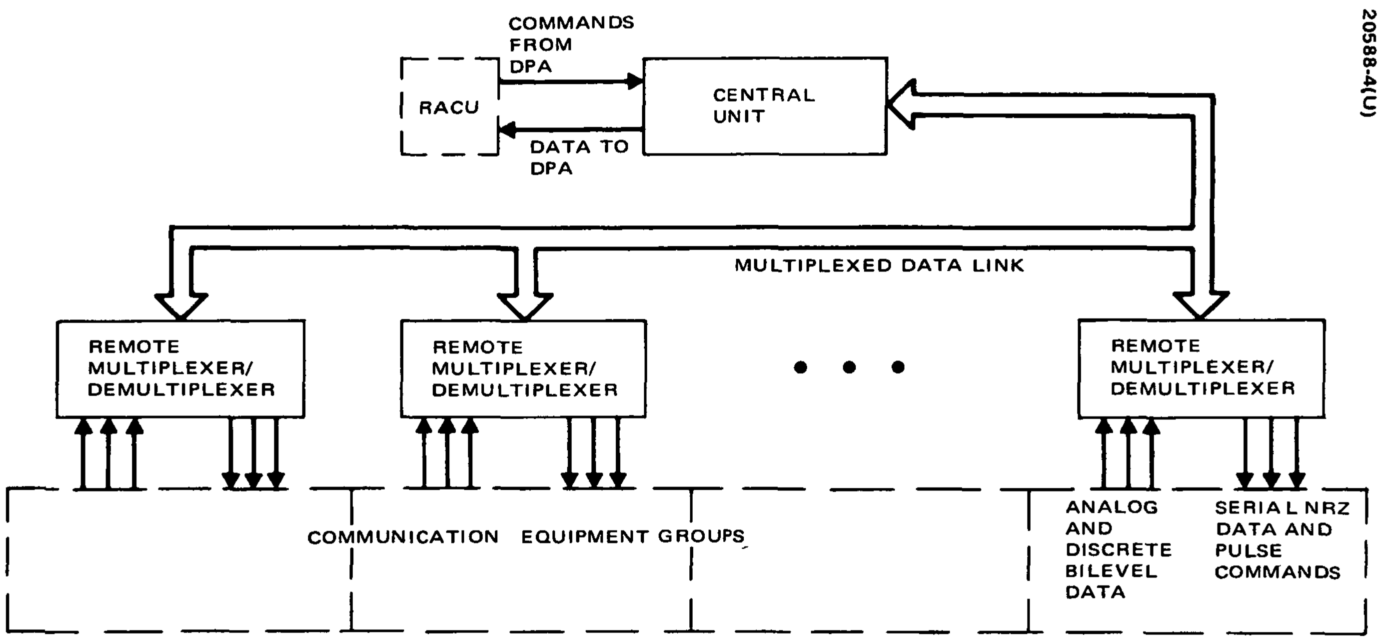


Figure 2-4. Communication Equipment Control and Monitoring

In operation, the central unit receives instructions and parameter values from the DPA in the form of 8 bit digital words from a remote acquisition and control unit (RACU). It processes these commands, determines which equipment is affected, and generates all implementation commands necessary to carry out the instructions. These are transmitted on the multiplex bus to the appropriate multiplexer/demultiplexer, which receives them and transmits command outputs to the equipment in the ECA or ICA. The command outputs provided include pulse command outputs and serial digital NRZ data outputs.

Pulse command outputs control the power-on and power-off status of ECA and ICA equipment, and set or reset other binary functions. The serial digital outputs set parameters in the units and distribute control information to the switches that connect the communication units into communication paths.

The central unit of the ECA and ICA control groups is a programmable command processor. The ECA control group central unit and the ICA control group central unit are identical except for their internal programs, which are adjusted to the requirements of the ECA or ICA. The central unit accepts commands and data from the DPA in the form of 8 bit words of serial NRZ data via a RACU. These command and data words conform to the format of Figure 2-5.

A similar format is used by the central unit to address the DPA (Figure 2-6). Positive verification is provided for all commands by repeating them as received. The command types are identical to those received with the addition of type 12 which is sent in the event parity does not check or the central unit perceives conflicting commands. The functions of the central unit include command reception, determination of unit availability, assignment of units for communication paths, generation of all commands to properly control the units, and two-way data transmission between the data processing assembly and the units of the ECA or ICA. These functions will be discussed individually.

Determination of Unit Availability. A memory within the central unit contains the status of each unit of equipment in the ECA or the ICA to determine whether the unit is available for assignment to a communication channel. If it is already in use, a tag identifying the communication link using it is stored with it, which prevents its reassignment. If the unit is not available because it is not functioning properly, this fact is stored. This nonfunctional tag is determined and ordered by the data processing assembly as part of its performance monitoring function. When a communication circuit is to be assembled, a communication link tag is supplied by the DPA. This tag is stored by the central unit in memory slots corresponding to all units that the central unit assigns to the communication link. The on/off status of units is also stored in memory by the central unit as it assembles and disassembles communication circuits.

1	2	3	4	5	6	7	8

20588-5(U)

BIT 1 = COMMAND IDENTIFICATION

LOGIC 1 = PRIMARY WORD OF A COMMAND
LOGIC 0 = SUPPLEMENTARY COMMAND WORD

FOR BIT 1 = 1

BITS 2-5 = COMMAND TYPE

	2 3 4 5	
0	0 0 0 0	= ESTABLISH MODE
1	0 0 0 1	= DISCONTINUE MODE
2	0 0 1 0	= TURN ON UNIT
3	0 0 1 1	= TURN OFF UNIT
4	0 1 0 0	= UNIT DEFECTIVE
5	0 1 0 1	= UNIT NO LONGER DEFECTIVE
6	0 1 1 0	= PARAMETER VALUE FOLLOWS
7	0 1 1 1	= REPORT DATA WORD
8	1 0 0 0	= FINISH ESTABLISHING MODE
9	1 0 0 1	= FINISH DISCONNECTING MODE
10	1 0 1 0	= RETAG UNIT
11	1 0 1 1	= IDENTIFY UNIT
12-15		= SPARE

DATA BITS 6, 7

PARITY BIT 8

FOR BIT 1 = 0

DATA BITS 2-8 OF 1ST SUPPLEMENTARY WORD, BITS 2-7 OF 2ND SUPPLEMENTARY WORD AND BITS 2-8 OF ADDITIONAL SUPPLEMENTARY WORDS

PARITY BIT 8 OF 2ND SUPPLEMENTARY WORD FOR BOTH SUPPLEMENTRY WORDS INCLUDED IN DATA FOR ADDITIONAL SUPPLEMENTARY WORDS AS REQUIRED

Figure 2-5. DPA to Control Group

EIGHT BIT NRZ WORDS TO DPA, CLOCK PROVIDED BY DPA

20588-6(U)

BIT 1 = IDENTIFICATION

LOGIC 1 = FIRST WORD OF MESSAGE

LOGIC 0 = OTHER WORDS

BITS 2-5 = DATA MESSAGE TYPE (COMMAND TYPE TO WHICH DATA IS A RESPONSE)

	2 3 4 5	
0	0 0 0 0	= ESTABLISH MODE
1	0 0 0 1	= DISCONTINUE MODE
2	0 0 1 0	= TURN ON UNIT
3	0 0 1 1	= TURN OFF UNIT
4	0 1 0 0	= UNIT DEFECTIVE
5	0 1 0 1	= UNIT NO LONGER DEFECTIVE
6	0 1 1 0	= PARAMETER RECEIVED
7	0 1 1 1	= DATA WORDS FOLLOW
8	1 0 0 0	= FINISH ESTABLISHING MODE
9	1 0 0 1	= FINISH DISCONNECTING MODE
10	1 0 1 0	= RETAG UNIT
11	1 0 1 1	= IDENTIFY UNIT
12	1 1 0 0	= PREVIOUS COMMAND INVALID
13-15		= SPARE

DATA BITS 6, 7

PARITY BIT 8

MESSAGE TYPES 0-6, 8-10 ARE SENT AS PROGRAMMED TO VERIFY EXECUTION OF COMMANDS

MESSAGE TYPES 7, 11

WORD	BITS	FUNCTION
P	6-7	REPEATS REQUEST TAG
S_n	2-7	REQUESTED DATA

Figure 2-6. Control Group to DPA

MANCHESTER CODED WORDS, 12 BITS PLUS SYNC AND PARITY

20588-7(U)

1 2 3	4 5 6 7 8 9 10 11 12 13 14 15	16
SYNC	DATA	P
	1 2 3 4 5 6 7 8 9 10 11 12	P

DATA FIELD	BIT 1	1	0
		COMMAND WORD	DATA WORD

BIT 1 = 1

BITS 2-5 = MULTIPLEXER/DEMULTIPLEXER ADDRESS

BITS 6-7 = INPUT OR OUTPUT TYPE

00 = PULSE OUTPUT

01 = DIGITAL OUTPUT

10 = DISCRETE INPUT

11 = ANALOG INPUT

BITS 8-12 = INPUT OR OUTPUT NUMBER

BIT 1 = 0

BITS 2-9 = DATA FOR SERIAL DIGITAL OUTPUT IDENTIFIED BY PREVIOUS COMMAND WORD

Figure 2-7. Central Unit to Multiplexer/Demultiplexer

Establishing Communication Circuits. When a communication circuit is to be assembled, the data processing assembly first transmits a command (type 0, Figure 2-5) giving the input location and the data path tag. It then transmits a number of turn-on commands (command type 2) and supplementary words identifying the type of unit to be used in the communication circuit. When the central unit receives one of these commands, it reads from its memory the status of units of the required type until it locates a unit of that type which is functioning properly and is available for use. The sampling order may be programmed to assure that all units of a type receive approximately equal use if desired. When a unit is found, the central unit assigns that unit to the communication circuit, transmits a pulse command to turn on the unit, and stores the tag associated with the communication circuit in memory to indicate that the unit is operating in that circuit. When a circuit is to be dismantled, a series of commands analogous to those sent to create the circuit is transmitted by the DPA. The tag of the circuit is given, and as units are commanded off, the central unit cycles through memory to find the unit with that tag, and sends pulse commands to turn off the units.

In addition to the turn-on and turn-off commands, serial digital commands are transmitted by the central unit to the circuit switches connecting the communication equipment as required to assemble or dismantle the communication circuits. To do this, the central unit retains in its memory the switch control bits necessary to access the input and output of each communication equipment unit. As the units for a communication link are identified, switch configuration control commands are generated from these input and output identification bits.

Two-Way Transmission of Data and Commands. The design of the central unit makes it possible for the DPA to access directly any pulse or serial digital output of any control group multiplexer/demultiplexer. This capability is used for loading parameter data serially into ECA and ICA units, and for directly commanding units on or off. The capability also exists for the DPA to directly address any analog input or discrete digital input word of any control group multiplexer/demultiplexer. When this is done, the central unit relays the command to the addressed multiplexer/demultiplexer and relays the data from the multiplexer/demultiplexer to the DPA along with a tag to identify it.

Remote Multiplexer/Demultiplexers. The remote multiplexer/demultiplexer interfaces with the control group data link and with units of the ECA or ICA. In general, one remote multiplexer/demultiplexer unit interfaces with each equipment group of a communication assembly, but the arrangement is adjustable to meet different group requirements.

Data are transferred between the control group central unit and the control group multiplexer/demultiplexer in 16 bit Manchester-coded data words. Each 16 bit word consists of a 3 bit long synchronization pattern, a 12 bit data field, and a parity bit. The data format from the control group central unit to the multiplexer/demultiplexers is shown in Figure 2-7. This

MANCHESTER CODED WORDS, 12 BITS PLUS SYNC AND PARITY

20588-8(U)

1 2 3	4 5 6 7 8 9 10 11 12 13 14 15	16
SYNC	DATA	P
	1 2 3 4 5 6 7 8 9 10 11 12	P

DATA FIELD	BIT 1	1 VERIFICATION	0 DATA

BIT 1 = 1

BITS 2-5 = MULTIPLEXER/DEMULTIPLEXER ADDRESS

BITS 6-7 = INPUT OR OUTPUT TYPE

00 = PULSE OUTPUT

01 = DIGITAL OUTPUT

10 = DISCRETE INPUT

11 = ANALOG INPUT

BITS 8-12 = INPUT OR OUTPUT NUMBER

BIT 1 = 0

BITS 2-9 = DATA FROM INPUT(S) IDENTIFIED IN PREVIOUS WORD

Figure 2-8. Multiplexer/Demultiplexer to Central Unit

format contains both command and data words. A command word simply defines a multiplexer/demultiplexer command output to be activated or an input to be sampled. A data word is sent following a command word if digital data are to be outputted.

Data from the control group multiplexer/demultiplexers to the central unit employ a format analogous to that used for transmissions to the remote multiplexer/demultiplexers from the central unit. This format is illustrated in Figure 2-8. Bit 1 of each data field identifies it as a verification word or a data word. Commands are returned as received to indicate that a command from the central unit has been executed. If a multiplexer/demultiplexer input must be sampled, the data from the sample are sent in a data word following the verification word.

Each remote multiplexer/demultiplexer provides up to 32 pulse command outputs, and up to 32 serial digital outputs that provide clock and NRZ data in 8 bit words. It accepts up to 32 analog inputs with a voltage range of ground to +5 volts, which it converts to 8 bit digital words for transmission, and up to 256 bilevel discrete data inputs which it also formats into 32, 8 bit words.

The remote multiplexer/demultiplexer takes action only in response to commands from the control group central unit. Automated test of the remote multiplexer/demultiplexer is performed by the DPA based on information gathered by sampling analog and discrete data inputs that are wired to internal points within the remote multiplexer/demultiplexers.

Reference and Test Equipment

Redundant reference frequency synthesizers are provided in the control group to stabilize all carrier and subcarrier oscillators. The fundamental frequency reference in the baseline is assumed to be derived from the digital data bus clock output from the RACU. If it is not convenient to provide a data bus clock with the stability necessary for the ECA requirements, local crystal oscillators could be used.

The two synthesizers provide reference bus carriers at two different nonharmonically related frequencies. Each equipment which utilizes the reference must be able to utilize either frequency by command. Two different frequencies are employed to prevent a noisy degradation of one reference from making both unusable and it also permits each reference to be monitored separately on the bus just as it appears to users.

Test translators to facilitate fault isolation and periodic testing are also included in this group. These are shown in Figure 2-3 between transmit and receive direction baseband switches.

Test translator AF provides three voice channel loops at the input to the ECA. These loops in conjunction with test signals from the CENTREX switchboard in the ICA determine that the voice circuits are satisfactory

through to the ECA input. Level controls are the only control provision necessary for this translator.

Test translator BE permits the evaluation of the input/output circuitry through the digital baseband encoders and decoders. To evaluate the digital-to-analog converters, it is necessary for the DPA to provide a simulated entertainment channel test signal on the systems data input. This translator could be a buffer between the outgoing and incoming circuits or it could have some capability to simulate signal degradation on the receive side.

Translator CD interconnects the transmit and receive direction at the subcarrier level. This necessitates a frequency translation capability in addition to channel characterization and gain control. At this point, all the modulator/demodulator types can be evaluated except the experiments data quadriphase modulator for which there is no comparable demodulator provided. Other provisions would be necessary to loop test this latter circuit.

The RF test translator interconnects the S band transmit and receive RF switches to provide loop tests at the RF carrier level. Here frequency translator gain control and variable frequency offset capability is needed. All carrier modulation/demodulation types can be evaluated, except the high rate quadriphase modulator for which no receive counterpart exists.

2.2 INTERNAL COMMUNICATION ASSEMBLY

The internal communication assembly is comprised of six equipment groups (see Figure 2-9):

1) Voice communication group

2) Video communication group

3) Music entertainment group

4) Audio bus group

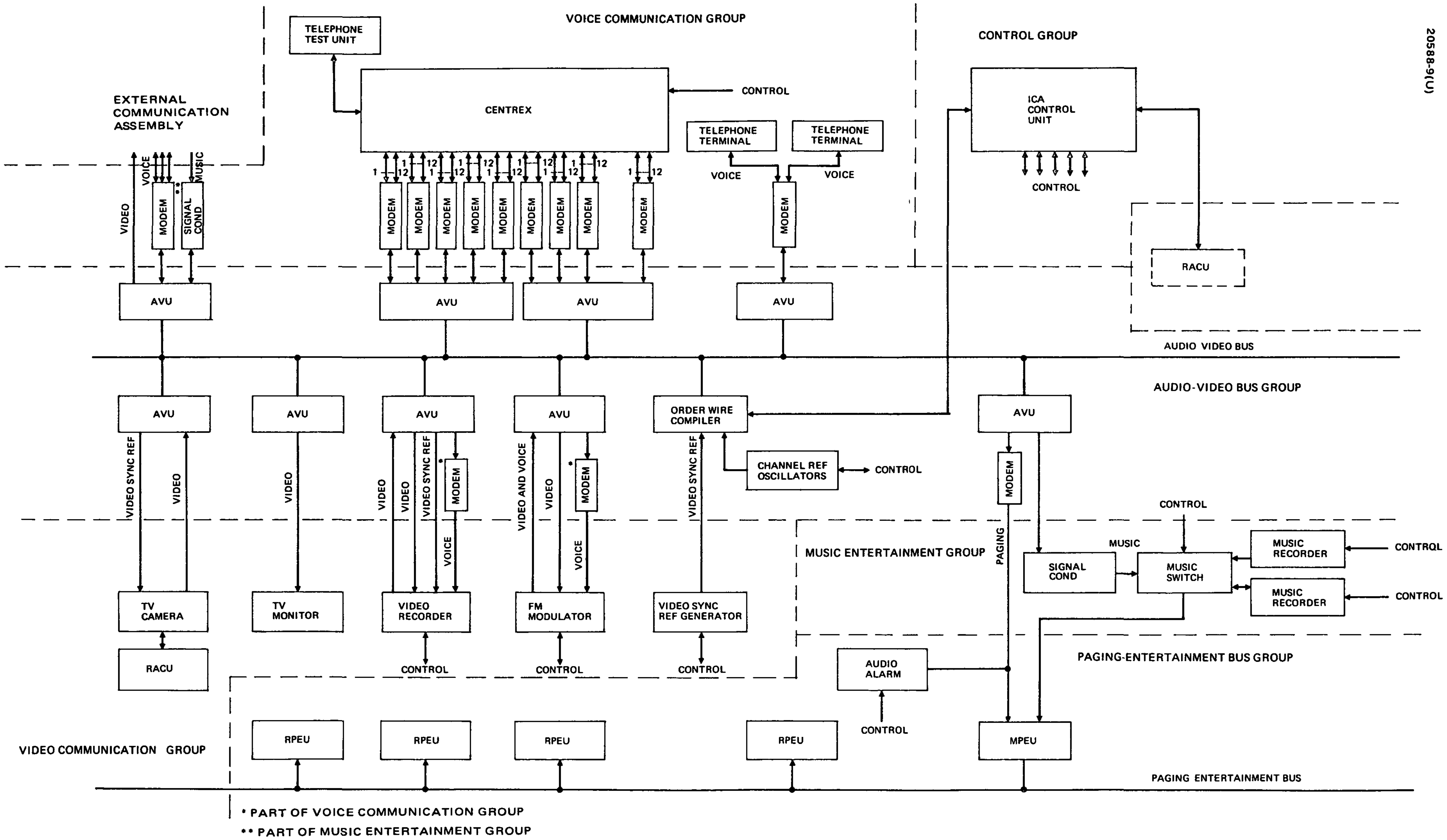
5) Paging-entertainment bus group

6) Control group

The following sections describe the equipment and performance of these groups.

2.2.1 Voice Communication Group

The voice communication group consists of two switchboards (one each in SM-1 and SM-4), four voice recorders, 30 telephone sets, and 20 modems. The operation of this group is similar to a conventional



• PART OF VOICE COMMUNICATION GROUP

•• PART OF MUSIC ENTERTAINMENT GROUP

Figure 2-9. Internal Communication Assembly Block Diagram

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CENTREX system. It provides internal communications by direct dialing other MSS telephone sets and provides direct dial access to terrestrial circuits via the ECA. It also has a conferencing capability which is used for conference calls and to call up voice recorders to provide a record of conversations. The paging facility is accessed by dialing a special code. This access is limited to the commander's telephone station.

Interconnection of the switchboard, the telephone sets, the paging-entertainment bus, the external RF circuits, and the voice recorders is provided by telephone modems and the audio-video bus group. The telephone modems frequency multiplex 12, 4 kHz telephone channels into a standard 48 kHz telephone group for transmission on the audio-video bus. The modems have both data and voice conditioning circuits.

2.2.2 Video Communication Group

The video communication group consists of two black and white and two color television cameras, nine television monitors, four video recorders, and auxiliary equipment. They form a closed circuit television network interconnected by the audio video bus group.

Cameras and recorders have a common video sync reference to provide uninterrupted viewing when switching between sources. An FM modulator is included in this group to add the aural subcarrier to the composite video for transmission to the ground. This subcarrier is used as the level reference pilot tone by the ECA modulator.

Video circuit switching is provided by audio-video bus channel selection and will be described in a later section. Remote television cameras which require mechanical manipulation for panning, focusing, etc. receive these commands from RACUs at their location.

Video recorders are assumed to be largely manually operated. However, when they have been manually set up to record or playback, either mode can be started and stopped by command from the control group.

2.2.3 Music Entertainment Group

There are four music recorders and two music switches in the music entertainment group. The recorders are normally used for playback of manually loaded tapes for distribution via the paging entertainment bus. The recorders are also used to record material received from the ground via the ECA. This latter circuit is brought to this group via a medium rate channel of the audio-video bus. Appropriate conditioning for transmission of the 10 kHz entertainment signal over a medium rate channel is provided in this group.

Start, stop, record and playback selection, and source selection are commanded by the control group.

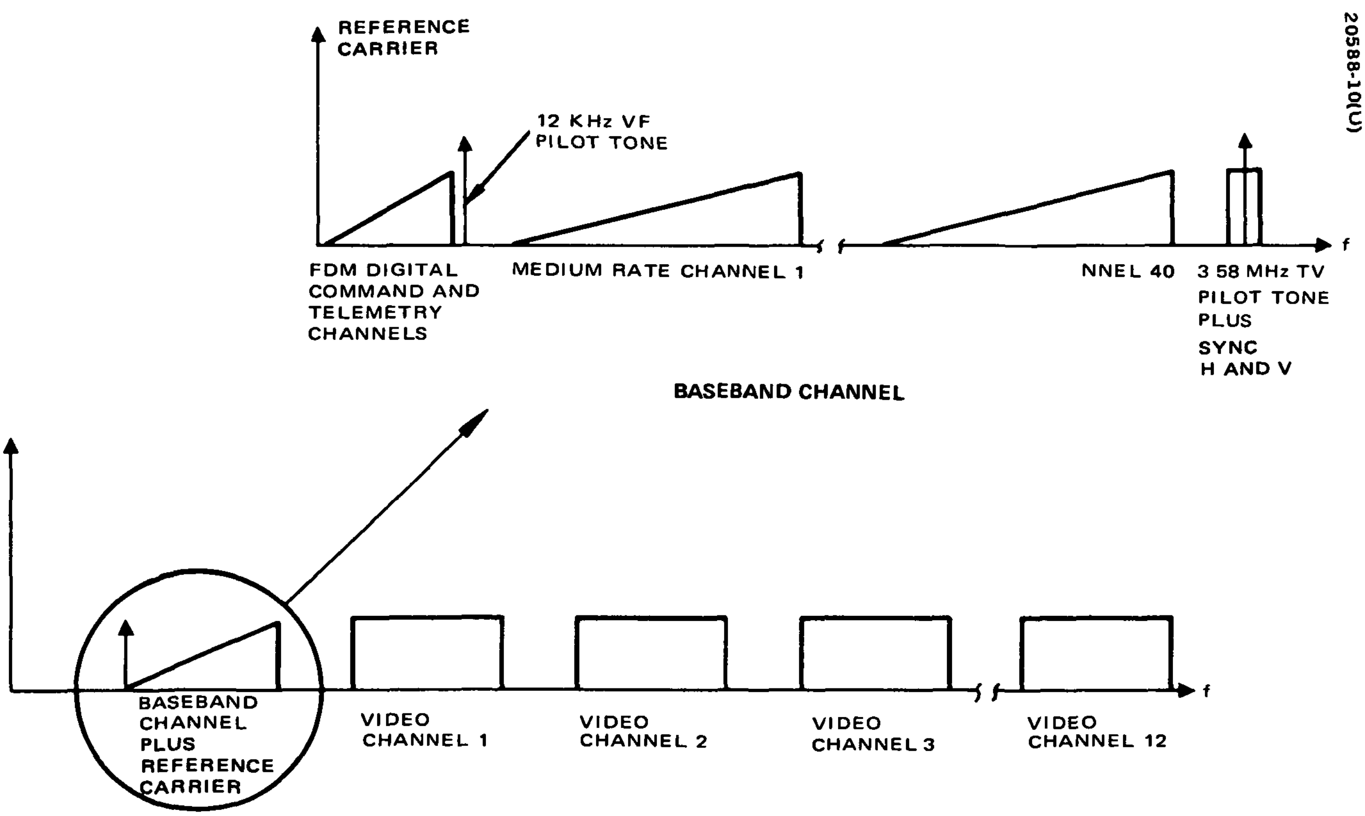


Figure 2-10. Audio Video Bus Signal Format

2.2.4 Audio-Video Bus Group

The audio-video bus group is central to the design of the ICA. It provides interconnection for all the voice and video communication units and with the ECA. It also provides video circuit switching and certain controlled accesses under the command of the control group.

For the baseline design, an FDMA signal format was selected as shown in Figure 2-10. A single sideband, AM baseband channel is provided for all the medium rate channels, the control channels, and the video reference signal. A reference carrier is transmitted and used by all audio-video units (AVU) for demodulating and modulating signals off and on the bus.

The command and monitoring signals between the orderwire compiler and the AVUs are contained in the signal group nearest the carrier. A 12 kHz pilot tone is provided for frequency translation and level reference for the 48 kHz medium rate channels.

Up to 70 medium rate channels can be accommodated in the baseband channel signal. The actual number used will depend on the physical locations of the telephone sets and how many are served by a single modem. Based on the current estimate of 20 modem units, less than half the capacity will be used including entertainment usage.

A 3.58 MHz color reference carrier is provided with horizontal and vertical sync reference modulation. This signal is inserted on the bus by the orderwire compiler.

The video signals connected to AVU inputs are frequency-modulated onto separate carriers in assigned channels on the bus. This carrier assignment is coordinated and commanded by the control group. By this means, the control group can route selected video signals between points as when it is instructed by the DPA to connect a particular television camera to the ECA for transmission to the ground.

Twenty AVUs are located throughout the MSS. Each AVU provides one duplex video circuit and one duplex medium rate circuit. The video output circuit has a manual selection mode so that a television monitor connected at that location can be tuned to video channels carrying entertainment programming.

As video channels carry both entertainment, and engineering and scientific data, AVUs in crew quarters are limited to manually accessing the entertainment channels only. This restriction is programmed into these particular AVUs by the control group.

The 3.58 MHz color reference signal and the 12 kHz VF pilot tone from the baseband channel are also available as outputs from each AVU. The 3.58 MHz is used to synchronize video sources and the 12 kHz pilot tone is used by the voice communication group modems for modulating and demodulating a voice channel group.

2.2.5 Paging-Entertainment Bus Group

The paging-entertainment bus group includes a master paging-entertainment unit (MPEU) and remote paging-entertainment units (RPEU) in all habitable compartments. The lines used for the hardwire intercom during station buildup are used as the bus. All transmission originates at the MPEU; the remote units can manually select from four entertainment channels. An audio alarm is included in this group which, when activated by the control group, overrides local volume controls at the RPEUs.

The paging input is connected to this group via the audio-video group from the telephone switchboard. This function also overrides the local volume control.

2.2.6 Control Group

The control group includes the command and monitoring equipment necessary to control and test the ICA. The command and monitoring equipment (central unit, data link, and multiplexer/demultiplexers) are identical to those described for the ECA in Section 2.1.

In the ICA, equipment performance parameters and configuration commands are distributed in a similar manner, although they are considerably less in number. This is because the audio and video equipments are best evaluated by observation and require considerable manual manipulation.

The audio-video bus group lends itself to electronic sensing and control similar to the ECA equipment, however, and such facilities are provided. As mentioned in the descriptions of previous groups, the assignment of video channels on the audio-video bus is controlled by this group, and individual AVUs are programmed for manual selection of these channels according to their location and use.

Also, although the telephone channel assignments are normally set up once between telephone sets and the switchboard, in the event an unsatisfactory channel is reported, the control group gives a new assignment to the switchboard and programs the affected AVU accordingly.

The control group also receives the alarm command from the DPA and activates the audio alarm in the paging entertainment group. Special telephone test equipment associated with the switchboard is also activated by the control group at DPA request.

3. SYSTEMS ANALYSIS

3.1 K BAND TDRS LINKS

The RF links between the modular space station (MSS) and the ground includes a two-way circuit via the tracking and data relay satellite (TDRS) at K band. This circuit is comprised of four RF segments as shown in Figure 3-1. (This figure also shows the notation which will be used in the analysis.)

The signals transmitted in the forward and reverse directions use FDM/FM modulation, and the basebands are considerably different from each other. The purpose of this analysis is to apportion the available TDRS EIRP in such a manner as to simultaneously satisfy RF carrier and baseband channel requirements for both the forward and reverse links.

The first objective is to assure that both links are received at their respective destinations above threshold for the FM demodulator. The carrier-to-noise ratio at the ground station is:

$$(CNR)_G = \frac{(CNR)_D \, (CNR)_R}{1 + (CNR)_D + (CNR)_R} \tag{1}$$

and at the MSS is:

$$(CNR)_M = \frac{(CNR)_U \, (CNR)_F}{1 + (CNR)_U + (CNR)_F} \tag{2}$$

$(CNR)_D$, $(CNR)_R$, $(CNR)_U$, and $(CNR)_F$ are the carrier-to-noise ratios of the four segments comprising the forward and reverse links using the subscript notation of Figure 3-1.

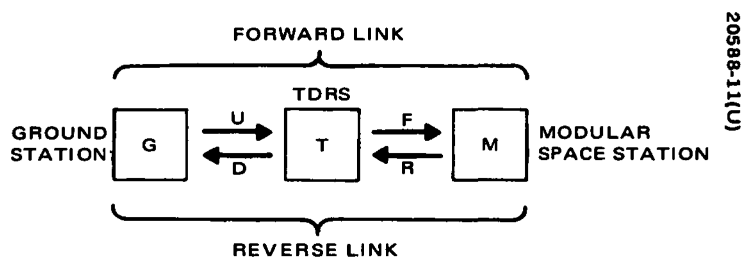


Figure 3-1. Nomenclature and Notation

3.1.1 Forward Link

For the forward link, the EIRP of the ground station may be relatively easily adjusted over a very large range as required by varying the transmitter power. The TDRS to MSS segment is constrained by the transmit parameters of the TDRS and the receive parameters of the MSS. Table 3-1 summarizes this relationship for the forward link. Table 3-2 gives the specified TDRS and MSS RF performance parameters.

Substituting the expressions for $(CNR)_U$ and $(CNR)_F$ into Equation 2 gives:

$$(CNR)_M = \frac{(PT)_G \, (G_R)_T \, (EIRP)_{TF} \times 1.738 \times 10^7}{(B_{RF})_U \, (B_{RF})_F + (B_{RF})_F \, (P_T)_G \, (G_R)_T \times 9.77 \times 10^3 + (B_{RF})_U \, (EIRP)_{TF} \times 1.78 \times 10^3} \qquad (3)$$

The product $(P_T)_G \, (G_R)_T$ has not been established by the TDRS system studies at this time, but to evaluate the more sensitive TDRS to MSS segment of the link, 47 dBw will be assumed. This might represent an earth coverage antenna and a 1 kw transmitter. Also, it will be assumed that the TDRS bandwidth and the MSS receiver bandwidth are matched:

$$(B_{RF})_U = (B_{RF})_F$$

With these substitutions Equation 3 becomes:

$$(CNR)_M = \frac{(EIRP)_{TF} \, 8.69 \times 10^{11}}{(B_{RF})_F \left[(B_{RF})_F + 4.885 \times 10^8 + (EIRP)_{TF} \, 1.78 \times 10^3\right]} \qquad (3')$$

This is plotted in Figure 3-2 with the RF bandwidth as the parameter.

3.1.2 Reverse Link

The power budgets for the reverse link segments are given in Table 3-3.

TABLE 3-1. FORWARD LINK RF BUDGET

Ground to TDRS Segment

Ground station transmitting power, dBw	$(PT)_G$
Ground station antenna gain, dB	60
Losses, dB	-217.9
Receive antenna gain, dB	$(GR)_T$
Received carrier power, dBw	$P_{TG} + G_{RT} - 157.9$
Noise density, dBw Hz^{-1}	-197.8
Signal bandwidth, dB Hz	$(B_{RF})_U$
Receiver noise power, dBw	$(B_{RF})_U - 197.8$
Carrier-to-noise ratio, dB	$(P_T)_G + (G_R)_T - (B_{RF})_U + 39.9$

$$(CNR)_U = \frac{(P_T)_G \times (G_R)_T \times 9.77 \times 10^3}{(B_{RF})_U}$$

TDRS to MSS Segment

Available TDRS EIRP, dBw	$(EIRP)_{TF}$
Losses, dB	-209.3
Receive antenna gain, dB	44.0
Received carrier power, dBw	$(EIRP)_{TF} - 165.3$
Noise density, dBw Hz^{-1}	-197.8
Signal bandwidth, dB Hz	$(B_{RF})_F$
Receiver noise power, dBw	$(B_{RF})_F - 197.8$
Carrier-to-noise ratio, dB	$(EIRP)_{TF} - (B_{RF})_F + 32.5$

$$(CNR)_F = \frac{(EIRP)_{TF} \times 1.78 \times 10^3}{(B_{RF})_F}$$

TABLE 3-2. RF PERFORMANCE PARAMETERS

Parameter	MSS	TDRS	Ground Station
T_S, °K	1200	1200	100
EIRP, dBw	58.5/52.4	52	—
G_R, dB	44	44.5	60
G_T, dB	44.5	—	60
Receive frequency, GHz	13.5 to 13.7	14.4 to 15.35	13.4 to 14.2
Transmit frequency, GHz	14.4 to 15.35	13.4 to 14.2	14.4 to 15.35
BW_{IF}, MHz	≤100	≤100	≤100
Path loss, dB	← 209.1 →		← 207.9 →
Atmospheric degradation, dB	—		10.0
Tracking loss, dB	0.2		—

Here, the RF performance parameters for the MSS and the TDRS are specified while the G/T of the ground station represents a conservative estimate of the current TDRS system study. Substituting the expressions for $(CNR)_R$ and $(CNR)_D$ into Equation 1 gives:

$$(CNR)_G = \frac{(EIRP)_{TD}\ 1.66 \times 10^{14}}{(B_{RF})_D\ (B_{RF})_R + (B_{RF})_R\ (EIRP)_{TD}\ 1.175 \times 10^5 + \frac{(B_{RF})_D}{1.413 \times 10^9}} \qquad (4)$$

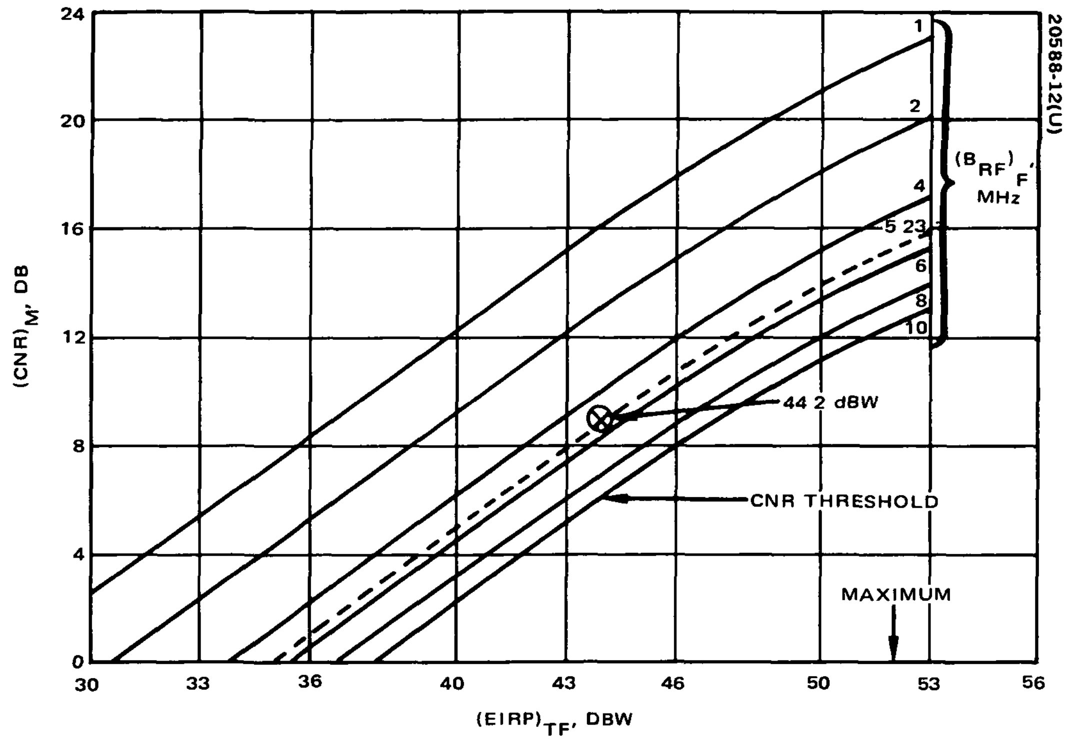


Figure 3-2. Forward Link CNR

TABLE 3-3. REVERSE LINK RF BUDGET

MSS to TDRS Segment

MSS EIRP, dBw	58.5
Losses, dB	-209.3
Receive antenna gain, dB	44.5
Received carrier power, dBw	-106.3
Noise density, dBw Hz^{-1}	-197.8
Signal bandwidth, dB Hz	$(B_{RF})_R$
Receiver noise power, dBw	$(B_{RF})_R$ - 197.8
Carrier-to-noise ratio, dB	91.5 - $(B_{RF})_R$

$$(CNR)_R = \frac{1.413 \times 10^9}{(B_{RF})_R}$$

TDRS to Ground Segment

Available TDRS EIRP, dBw	$(EIRP)_{TD}$
Losses, dB	-217.9
Receive antenna gain, dB	60
Received carrier power, dBw	$(EIRP)_{TD}$ - 157.9
Noise density, dBw Hz^{-1}	-208.6
Signal bandwidth, dB Hz	$(B_{RF})_D$
Receiver noise power, dBw	$(B_{RF})_D$ - 208.6
Carrier-to-noise ratio, dB	$(EIRP)_{TD}$ - $(B_{RF})_D$ + 50.7

$$(CNR)_D = \frac{(EIRP)_{TD}\ 1.175 \times 10^5}{(B_{RF})_D}$$

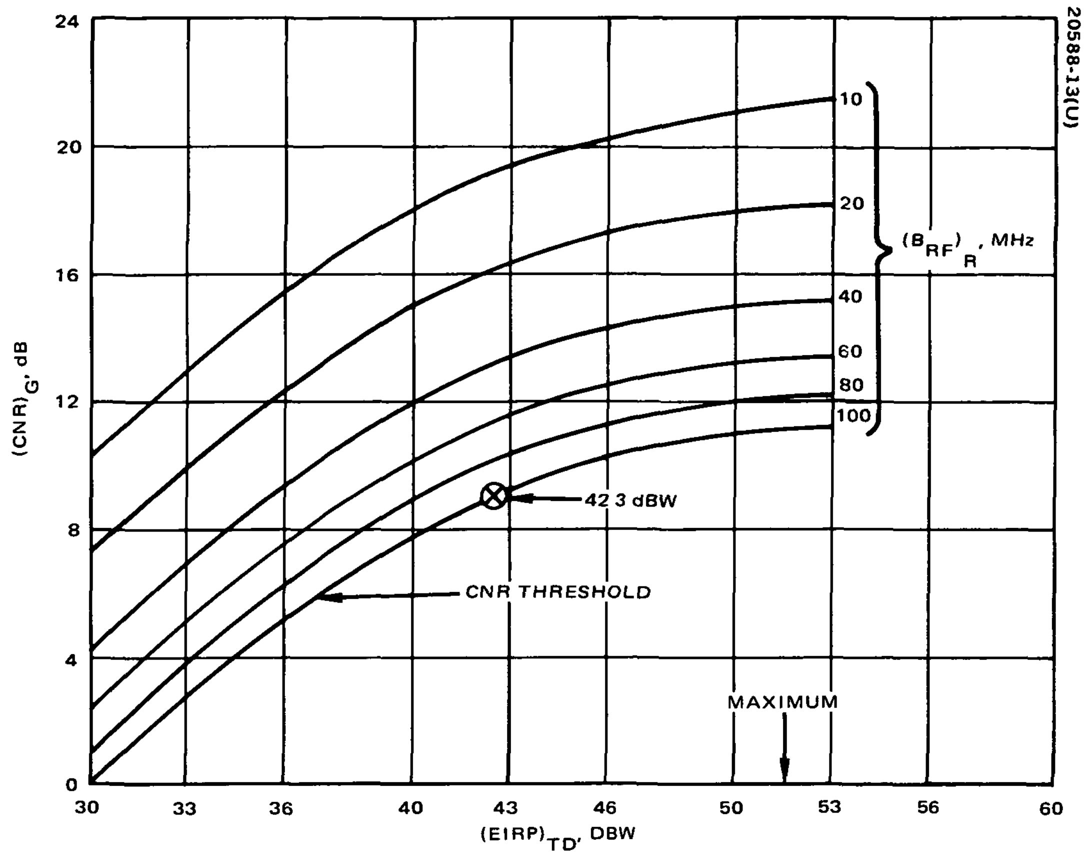
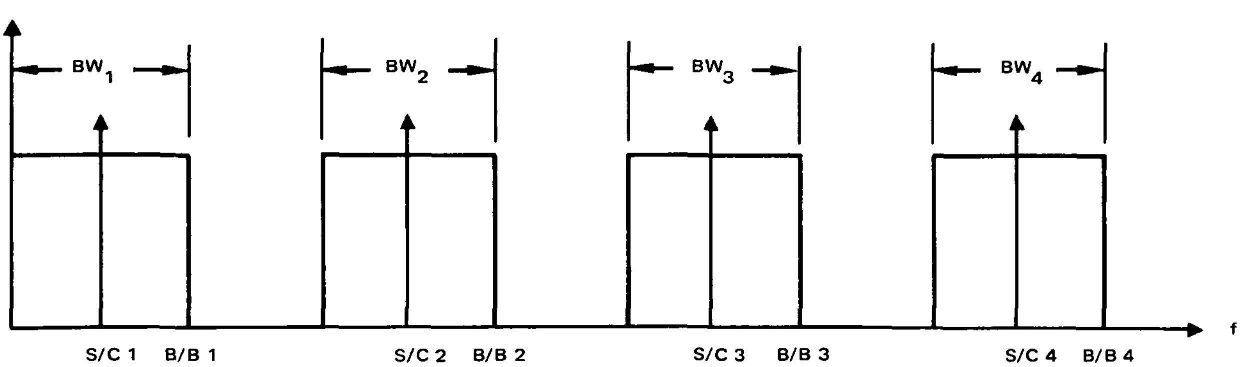


Figure 3-3. Reverse Link CNR



$S/C\ 1 = \frac{BW_1}{2}$ $\qquad$ $B/B\ 1 = BW_1$

$S/C\ 2 = 1\ 3\ BW_1 + \frac{BW_2}{2}$ $\qquad$ $B/B\ 2 = 1\ 3\ BW_1 + BW_2$

$S/C\ 3 = 1\ 3^2\ BW_1 + 1\ 3\ BW_2 + \frac{BW_3}{2}$ $\qquad$ $B/B\ 3 = 1\ 3^2\ BW_1 + 1\ 3\ BW_2 + BW_3$

$S/C\ 4 = 1\ 3^3\ BW_1 + 1\ 3^2\ BW_2 + 1\ 3\ BW_3 + \frac{BW_4}{2}$ $\qquad$ $B/B\ 4 = 1\ 3^3\ BW_1 + 1\ 3^2\ BW_2 + 1\ 3\ BW_3 + BW_4$

Figure 3-4. Baseband Channelization Format

With the assumption of matched bandwidths on the two segments, $(B_{RF})_R = (B_{RF})_D$, Equation 4 becomes

$$(CNR)_G = \frac{1.66 \times 10^{14} \, (EIRP)_{TD}}{(B_{RF})_R \left[(B_{RF})_R + (EIRP)_{TD} \, 1.175 \times 10^5 + 1.413 \times 10^9 \right]} \qquad (4')$$

This is plotted in Figure 3-3 with RF bandwidth as the parameter as in the previous case.

Figures 3-2 and 3-3 are useful for allocating TDRS EIRP in conjunction with relations describing the baseband signal to noise and RF bandwidth to be developed next.

3.1.3 Baseband Signal Requirements

An FDM baseband design requires consideration of subcarrier frequency selection and guard bands between channel signal bandwidths. As an optimized design is beyond the scope of this activity and would be premature at this stage of the conceptual system design, a general, representative approach will be taken to demonstrate feasibility and provide sufficient parameter margins for later detailed design. This is shown in Figure 3-4 which gives the significant baseband parameters in terms of subcarrier bandwidth. The channel spacing is predicated on the performance of 7-pole Butterworth filters with adjacent channel rejection at -20 dB (minimum). This is neither the optimum passband characteristic for all signal types, nor do all subcarrier channels require the same amount of adjacent channel rejection. It is representative, however, as angle-modulated subcarriers require a linear phase/frequency relation and a majority of the subcarriers require an S/N of approximately 10 dB. Thus adjacent channel signal components would contribute only one-tenth or less of the channel noise.

The signal characteristics in the baseband channels are summarized in Table 3-4. These data are developed from Table II of Reference 2. In the baseline, the voice channels and the entertainment channel are digitized, the former using (approximately) 20 kbps delta modulators and the latter using 7 bit PCM.

All signal sources, except the television signals, are impressed on subcarriers before combining into the baseband. This is done to permit each channel to be modulated and demodulated independently of the others in order to provide the most flexible arrangement. The TV, however, would require excessive bandwidth if symmetric subcarrier modulation was used so it is located in the lowest portion of the baseband where it modulates the carrier directly.

TABLE 3-4. BASEBAND SIGNAL CHARACTERISTICS

Signal	Bandwidth/ Data Rate	Subcarrier Bandwidth	Subcarrier Modulation	Subcarrier S/N, dB
Voice (3)	60 kbps	90 kHz	2ø PSK	9.2
Music (7 bit PCM)	140 kbps	210 kHz	2ø PSK	9.2
Text and graphics	500 kbps	750 kHz	2ø PSK	9.2
Systems data*	50 kbps	75 kHz	2ø PSK	9.2
Systems data**	500 kbps	750 kHz	2ø PSK	9.2
Experiments data	5 Mbps	4 MHz	4ø PSK	12.0
Control	10 kbps	15 kHz	2ø PSK	9.2
Computer data	500 kbps	750 kHz	2ø PSK	9.2
Facsimile	500 kHz	1.0 MHz	NBFM	10.0
PN range code	1 Mbps	1.5 MHz	2ø PSK	-30.0
Color TV (includes aural subcarrier)	4.55 MHz	—	—	39.8
Black and white TV	2.9 MHz	—	—	39.8

*S band.
**K band.

The subcarrier channel bandwidths are set by allowing 1.5 Hz per symbol per second for biphase and somewhat more for quadriphase. Facsimile transmitted as NBFM requires twice its highest baseband frequency.

The digital subcarrier signal-to-noise ratios are calculated for a 10^{-5} BER in the channel bandwidth. The PN range code and the facsimile S/N requirements are just estimates based on typical practice as no quality requirements have been given. The color TV requirement is the rms signal to rms noise ratio equivalent to the CCIR recommended 56 dB peak-to-peak signal to weighted rms noise (10.2 dB noise weighting plus 6 dB form factor). As no standard is given for the narrowband black and white TV specified, the same S/N requirement is assumed for it.

Using the channelization format of Figure 3-4, the signal characteristics of Table 3-4, and the simultaneous signal modes from Table III of Reference 2, the worst case baseband signals for the K band link are determined. These are given in Table 3-5.

3.1.4 Signal Design

In a balanced system design, the S/N in the carrier and subcarrier channels should be at their minimum operating points simultaneously. This corresponds to a 6 dB carrier-to-noise ratio in the IF assuming a practical threshold extension demodulator. Thus Equation 7 of Appendix A is used to calculate the modulation index for each subcarrier channel for the minimum required channel S/N for a 6 dB carrier-to-noise ratio:

$$\beta_n = \sqrt{\left(\frac{S}{N}\right)_n \cdot \frac{B_{BP_n}}{6\ B_{RF}}} \qquad (5)$$

Here $(S/N)_n$ is the appropriate S/N in the channel of interest taken from Table 3-4 and the channel bandwidth B_{BP_n} is from Table 3-5 and Figure A-1 of Appendix A.

B_{RF} can be determined from Equation 12 of Appendix A:

$$B_{RF} = 2\left[\beta_1 f_{u1} + \beta_2 f_{u2} \cdots + (\beta_n + 1) f_{un}\right] \qquad (6)$$

Combining Equations 5 and 6 gives the expression for B_{RF}:

$$B_{RF}^{3} - 4 f_{un} B_{RF}^{2} + 4 f_{un}^{2} B_{RF} - 4\left[D_1 + D_2 \cdots + D_n\right]^2 = 0 \qquad (7)$$

where

$$D_n = f_{un} \sqrt{\left(\frac{S}{N}\right)_n \frac{B_{BP_n}}{6}}$$

This has been calculated for the forward and reverse links; the parameter values are given in Table 3-6.

TABLE 3-5. K BAND BASEBAND SIGNAL CHARACTERISTICS

Link	Mode*	Baseband Channel	Service	Channel Bandwidth	Subcarrier Frequency	Highest Baseband Frequency
Forward	3	1	FAX	1. 0 MHz	500 kHz	1. 0 MHz
Forward	3	2	Entertainment plus 3 voice (TDM)	300 kHz	1. 45 MHz	1. 6 MHz
Reverse	7	1	Color TV	4. 55 MHz	—	4. 55 MHz
Reverse	7	2	FAX	1. 0 MHz	6. 415 MHz	6. 915 MHz
Reverse	7	3	3 voice (TDM)	90 kHz	9. 045 MHz	9. 09 MHz

*Reference 2, Table III.

TABLE 3-6. K BAND TDRS LINKS SIGNAL DESIGN PARAMETERS

Forward Link	
B_{RF}	5.23 MHz
β_1	0.564
β_2	0.282
Reverse Link	
B_{RF}	98.8 MHz
β_1	8.56
β_2	0.13
β_3	0.0355

3.1.5 TDRS EIRP Allocations

Referring back to Figures 3-2 and 3-3 which show forward and reverse link performances, respectively, and using the RF bandwidths from Table 3-6, it is observed that at carrier threshold (C_{NR} = 6 dB), the forward link requires 41.1 dBw and the reverse link 37 dBw. Both links together require 42.5 dBw which is 9.5 dB below the saturated output power of the TDRS.

This latter figure can be misleading, however, as it is not a useful margin since the nonlinearity of the TDRS final amplifier at this point would invalidate the assumptions of the analysis which ignores IM products in the signal bandwidth. On the other hand, it can be observed from the curves that if the operating point for each link was set for a 3 dB margin the total EIRP required is 46.4 dBw which is 5.6 dB below saturated output. This is sufficient to assume linearity in the input/output relation for typical TWT characteristics in the CNR range of interest. (See Reference 3 and especially Section 4.6 therein.)

3.2 S BAND ANALYSES

3.2.1 Shuttle/MSS Links

MSS operation in conjunction with a shuttle vehicle requires a data interchange, two-way voice communications, and turnaround ranging originating from either vehicle. (Tables II and III from Reference 2.) These communications are to be conducted via S band systems with characteristics as given in Table 3-7 (compiled from References 1 and 4).

Consideration of the link capacity to and from the shuttle as reflected in the C/N_0 parameter shows both links are rather low capacity at the maximum range and are imbalanced by 7.7 dB. The link for the MSS to the shuttle is clearly deficient and needs to be corrected. The noise power density in particular seems to be unnecessarily high; observe that it is 12 dB higher than the MSS. It is also not in agreement with the data utilized on the present TDRS system studies (Reference 4). Accordingly, the noise power density as used in that study (-199 dBw Hz^{-1}) will be employed here (the numbers in parentheses). Even with this correction, it is clear that the full communication requirements (including the ranging) cannot be met at this distance. What needs to be determined is what communications can be provided at the maximum range and at what range the full requirements are satisfied.

It is assumed that the lack of ranging ability at the maximum range is not a problem as accuracies required for rendezvous maneuvers at that point could be supported by ground tracking data or an exchange of self-determined orbital data between the shuttle and the MSS. Similarly, voice capability, while always desirable, would seem to have a lesser value at the maximum distance.

TABLE 3-7. S BAND RF PARAMETERS

Parameter	MSS	GND	Shuttle	TDRS
EIRP, dBw	14.8	92.0	10.5	47.0
Losses re MSS, dB	—	-153.0	-158.0*	-192.0
Receive antenna gain, dB	0	52.0	0	34.0
Noise power density, dBw Hz^{-1}	-202.0	-208.0	-190.0 (-199)	-200.0
C/N_0 (to MSS), dB Hz	—	141.0	54.5	57.0
C/N_0 (from MSS), dB Hz	—	121.8	46.8 (55.8)	57.8

*450 n. mi. range.

Accepting the constraints of the RF performance of the shuttle and MSS as specified, the signal design becomes a matter of selecting the proper order and form to implement the portions of the total desired capability that are feasible at successive distances. What is needed is a design that permits the successive addition of independent signals as the RF link can support them without disrupting the ongoing circuits.

Three alternatives may be considered to provide this capability: 1) TDM with flexible signal and frame structures, 2) an FDM baseband, and 3) FDM carriers. The first and third alternatives are conceptually the most efficient choices as they permit direct PSK carrier modulation and hence can take advantage of error correction channel encoding to obtain near optimum performance.

The disadvantage of both these techniques is that their efficiency is obtained by means of highly structured composite signal designs that permit relatively little variation in their separate constituents. That is, the TDM design would require synchronous voice, data and ranging sources which would require that turnaround ranging be regenerated and all sources would be constrained to mutually compatible rates.

An FDM carrier approach that used one carrier for the ranging and separate data and voice carriers placed in the upper and lower null points in the ranging spectrum is not as constraining for the MSS which has several S band transmitters. However, it would mean that three transmitters would have to be employed just for this link, denying them to the ground and DRAM links. Moreover, the shuttle is not likely to have three separate S band transmitters available, which means it would have to operate one transmitter in a multicarrier mode with attendant backoff losses and IM problems.

In view of these considerations, the FDM baseband approach was selected as the baseline at this time. While it does not provide the maximum performance, it does permit the incremental addition of different signals with a minimum of constraints and provides a useful data rate at the maximum range, and these characteristics are considered of more importance at the present time.

Table 3-8 summarizes the characteristics of this link with the foregoing assumptions. The FDM baseband is comprised of three subcarrier channels as shown. The links are designed with fixed deviations for each of the channels so that the others may be added as the link permits without changing those in service. (The data shown are based on the poorest link direction, i. e., from the shuttle to the MSS.)

3. 2. 2 MSS/TDRS Links

In the case of the TDRS link which acts as a backup to the K band primary link, considerations lead to an alternative signal configuration. Here, there is no concern of adding additional services as the link improves;

TABLE 3-8. MSS/SHUTTLE LINK PERFORMANCE

Service		B_{RF}, Hz	Range, n. mi.	Margin, dB
Channel 1		4.95×10^4	450	1.6
Channels 1 and 2		4.195×10^5	150	2.9
Channels 1, 2, and 3		3.588×10^6	50	2.1
Channel	**Data**		**R_b at BER = 10^{-5}, bps**	**β**
1	Low rate system data		10^4	0.65
2	Medium rate system data plus one voice		5×10^4 (data) 2×10^4 (voice)	0.6
3	Turnaround ranging		10^6	0.0265

the small reduction in link loss as the MSS passes through the TDRS visibility is negligible. Also, since this is backing up a high capacity primary service, it should be designed to handle as much communication as possible. And lastly no ranging is required so that there is no particular difficulty in combining the individual data streams. Accordingly, the selected modulation technique is direct PSK carrier modulation with channel encoding and a TDM baseband.

Table 3-9 summarizes the performance of these links. The data requirements, 70 and 30 kbps, are comprised of one 20 kbps voice and 50 kbps of systems data in the first instance and voice plus 10 kbps of control data in the second.

3.2.3 MSS/Ground Links

The direct links between the MSS and the ground at S band are very conservatively designed as shown in Table 3-7. In the table, the C/N_o for the uplink and the downlink are 141 and 121.8 dB Hz, respectively. Because of the excessive performance margin provided by the MSS and ground equipment as designed, there is no optimization to be performed as there are no opposing critical parameters.

The minimal communication requirements for the full station operation are composed of voice, data, and turnaround ranging. Phase rather than frequency modulation was selected for this link to provide an alternative type of implementation.

TABLE 3-9. MSS/TDRS GROUND LINK PERFORMANCE

MSS to TDRS to Ground	
Carrier-to-noise power density at TDRS	57.8 dB Hz
Carrier-to-noise power density (TDRS/ground)	93.0 dB Hz
C/N_o (MSS/TDRS/ground)	57.8 dB Hz
Bit rate (70 kbps)	48.5 dB Hz
E_b/N_o received	9.3 dB
E_b/N_o required	5.0 dB
Margin	4.3 dB
Ground to TDRS to MSS	
Carrier-to-noise power density (ground/TDRS)	86.9 dB Hz
Carrier-to-noise power density (TDRS/MSS)	57.0 dB Hz
C/N_o (ground/TDRS/MSS)	57.0 dB Hz
Bit rate (30 kbps)	44.8 dB Hz
E_b/N_o received	12.2 dB
E_b/N_o required	5.0 dB
Margin	7.2 dB

To calculate the link performance, the signal bandwidth was chosen arbitrarily to fit both links into 13 MHz leaving the C/N unconstrained. The signal parameters are given in Table 3-10.

Channel 1 carries the turnaround ranging, channel 2, three multiplexed voice channels, and channel 3 is calculated for text and graphics on the uplink and 50 kbps systems data on the downlink. The uplink operates with a carrier-to-noise ratio of 27.7 dB and a margin of 44.7 dB. The downlink carrier-to-noise ratio is 24 dB, with a 30.2 dB margin.

TABLE 3-10. MSS/GROUND LINKS SIGNAL DESIGN PARAMETERS

<u>Uplink</u>	
B_{RF}	7.25 MHz
β_1	8.39×10^{-4}
β_2	1.874×10^{-2}
β_3	5.4×10^{-2}
<u>Downlink</u>	
B_{RF}	5.75 MHz
β_1	1.443×10^{-3}
β_2	3.23×10^{-2}
β_3	2.94×10^{-2}

3.3 CONTROL FUNCTIONAL DESIGN

3.3.1 Requirements

The control design requirements are developed from:

1) The overall communication design of the MSS

2) The MSS system control design philosophy

3) MSS communication mode requirements

4) Self-test and checkout requirements

For this analysis, the communication equipment design is assumed to be that developed by NAR/ITT (Reference 1). The MSS control design philosophy as it pertains to the ECA and ICA is also derived from the MSS system design, the principal rule being that the ECA and ICA resources are under the control of the data processing assembly. The communication mode requirements are the mission communication circuits and traffic requirements through MSS buildup and full operations as specified by NASA/MSC (Reference 2).

The self-test and checkout requirements are those developed on the McDonnell Douglas System Checkout Study (Reference 5) as applicable to the NAR/ITT system design. This study arranges these requirements in the four categories described in Table 3-11.

TABLE 3-11. SELF-TEST AND CHECKOUT FUNCTIONS

Category	Description
Status monitoring	Monitoring of selected parameters using operational signals and comparison with stored limits to make qualitative assessments of circuits and equipment
Periodic testing	Preplanned tests using test signal stimuli conducted as part of equipment maintenance routines
Trend analysis	Processing of sampled status monitoring and periodic test measurements to detect trends in circuit and equipment performance
Fault isolation	Programmed procedures utilizing stored equipment status data and test signal stimuli to isolate faults to line replaceable unit level

TABLE 3-12. CONTROL PARAMETER TYPE AND USAGE SUMMARY

Parameter Type	Total	Operations	Status Monitoring	Periodic Test	Trend Analysis	Fault Isolation
Stimuli						
Bilevel	241	141		79		235
Digital	52	52		38		49
RF	46			15	1	46
Total stimuli	339	166	0	132	1	330
Measurements						
Analog	271	42	33	164	26	263
Bilevel	243	146	3	62		236
Digital	42	28	4	14		37
Total measurements	556	216	40	240	26	536
Total parameters	895	382	40	372	27	866

In Table 3-11, the significant difference between the status monitoring and periodic testing functions is that the former utilizes operational signals only and the latter special, calibrated test signals. For control design considerations, the periodic testing requirements have greater significance since test stimuli commands must be coordinated with measured responses and many more parameters are evaluated. (For the McDonnell Douglas design, 40 parameters were measured for status monitoring as compared to 240 parameters and 132 test stimuli for periodic testing.)

Trend analysis is a data processing function that utilizes selected parameter measurements developed for status monitoring and periodic testing, so there is little additional impact on the ECA and ICA control design. Fault isolation, on the other hand, imposes many unique requirements not provided for in the previous functions. Of particular importance to control design is the necessity to provide sufficient, well-defined interfaces in order to isolate a fault to a single unit in a long and complex chain. It is particularly important when considering this function to be aware that the control circuits comprise multiple feedback paths around the communication equipment which can give rise to all sorts of difficulty if their design is not carefully integrated with that of the communication equipment.

The number of control parameters that would typically be required is given in Table 3-12 which is derived from Reference 5. As these data were developed against the McDonnell Douglas MSS configuration, they are not exact for the NAR design, although they do describe the order of magnitude relationship.

The first column gives the total number of stimuli and measurements; the next five columns show how many of these parameters are used for operations, status monitoring, periodic testing, trend analysis, and fault isolation, respectively. Stimuli are command words or voltage levels used for selection or on/off control, and RF test signals. Measurements are made of analog signals, bilevel voltages (or currents), and digital words or sequences.

Table 3-12 shows that about 42 percent of the total is used for normal communication operations and the remainder for test and checkout modes. For the McDonnell Douglas configuration, this is about the same percentage as is required for the other subsystems of the MSS.

For this study, the test and checkout parameters developed on the McDonnell Douglas study will be applied to the NAR system directly consistent with the latter's ECA/ICA design. The control parameters, however, will be determined by the requirements developed from the NAR ECA/ICA design and the present analysis.

3.3.2 Control Functions

The control design is conducted by identifying the discrete command, monitoring, and processing steps required and, based on an assessment of the requirements, assigning the responsibility for implementation to either

TABLE 3-13. CONTROL FUNCTIONS

Function	Description
1. Configuration/mode selection	Decision to establish a particular internal and/or external communication circuit or operating mode based on: 1) a service request, 2) knowledge of available facilities, 3) MSS operating mode, and 4) operational constraints
2. Configuration command(s)	Coordinated command(s) to associated and affected assemblies to implement a specific configuration or mode change.
3. Equipment selection	Decision to interconnect specific equipment in a specific manner to implement a configuration/mode command based on detailed knowledge of equipment availability
4. Implementation command(s)	Coordinated commands to all affected equipments to establish circuits via specific unit
5. Operational constraints	Knowledge of operational limitations to utilization of resource
6. Circuit performance status	Knowledge of quality of operational circuits
7. Equipment performance status	Knowledge of quality of operational equipments
8. Equipment availability	Accountability of operational/standby status of pooled and/or redundant equipment
9. Parameter measurement	Detection of selected physical quantities related to circuit and equipment performance
10. Signal conditioning	Current, voltage, or time buffering
11. Limit level detection	Comparison of measured quantities against stored minimum/maximum limits
12. Parameter computations	Sampling, averaging, and normalizing measured parameters for test and fault isolation
13. Test signal generation	Generation of specially designed calibrated signals for period test measurements
14. Test program	Sequence of commands to generate and measure signals for operational and periodic testing
15. Fault isolation program	Sequence of commands to generate and measure signals for fault isolation
16. Trend analysis	Storing and processing of measured parameters to detect trends in signal and equipment performance

the data processing assembly or the ECA/ICA. Table 3-13 represents the first step in this procedure, the identification of the discrete control functions.

The functions are not listed in any particular order, and the several MSS operational and test modes will use the various control functions in differing combinations and sequences, although all begin with steps 1, 2, 3, and 4. From that point on, depending on whether a change in operational communication circuits or a test mode has been commanded, the sequence of functions will vary appropriately.

The modes referred to in these steps describe various communication configurations (e. g., K band TDRS, MSS to shuttle, etc.), backup communications such as S band TDRS, the two special test configurations, periodic testing and fault isolation, and others as may be appropriate.

In functions 1 and 2, and 3 and 4, the decision function has been delineated from the enabling command function in recognition of the different form of typical implementation for these two functions. For instance, the decision process would typically be software (programming), whereas the commands might be words stored in a programmable read-only memory. To retain visibility of these design differences when assigning responsibility for the design and implementation, it is useful to consider them as two discrete functions.

Function 5, operational constraints, is a catchall to distinguish those factors that affect the decisions in step 1, but are not directly sensed by the DPA. Examples would be ground station and TDRS visibility and scheduling, frequency coordination, etc.

Functions 6 and 7 are determinations based on status monitoring measurements. These are bookkeeping functions that retain an updated account of the performance quality of circuits and equipment, respectively.

Function 8 is also a bookkeeping function to retain a knowledge of the utilization of pooled facilities such as audio video bus channels, modulators, etc.

Function 9 is the actual detection (or measurement) of physical quantities such as mounting plate temperature, RF signal level, helix current, selector switch position, etc. Generally, these will be analog or discrete quantities of arbitrary magnitude, size, and time base.

Signal conditioning, function 10, is employed to adapt these measured parameters to a form appropriate for processing or transmission. Additionally, signal conditioning is performed on command signals to accommodate the input requirements of the controlled circuits.

Limit level detection, function 11, is a requirement of the status monitoring self-check function. In this procedure, a particular parameter

measurement is quantitatively compared with a stored reference level (representing a limiting value) and an excess is recognized.

Parameter computations, function 12, concerns preprocessing of parameter measurements for test procedures. Typically this would involve maintaining a running average of a test parameter for periodic readout to a test program on a minute or hourly basis.

Test signal generation, function 13, is the generation of special test signals (stimuli) for quantitative evaluation of equipment performance as a part of periodic testing or fault isolation.

The test program function is the programming required to direct and evaluate the ECA and ICA equipment performance measurements for either status monitoring or periodic testing. This function is distinguished from the fault isolation program because the latter involves a significantly more comprehensive interaction with the ECA and ICA designs. Whereas the test program function performs routine observations of the equipment according to a preestablished and relatively fixed procedures, the fault isolation program involves an iterative process of test and deduction.

Trend analysis, function 16, is the data processing (programming and memory) required to perform the trend analysis checkout function.

3.3.3 Control Design Alternatives

With the discrete control functions appropriately identified, the next step in the analysis is to assign the responsibility for implementing these functions to either the DPA or the ECA/ICA. To illustrate the range of alternatives possible, two extreme approaches were first considered. Alternate A assigns the maximum feasible control function responsibility to the DPA and its extension, the RACU. Alternate B places the maximum control function responsibility on the ECA and ICA. In both cases, they must observe the ground rules that the ECA and ICA are under the control of the DPA at all times and that maximum use is made of the DPA's data processing facilities.

In Alternate A, each controlled unit of the ECA and ICA would have one or more parallel hardwire circuits to RACU input/output channels. These circuits would connect the DPA (via the RACU) directly to the circuits to be controlled or monitored. A minimum of control circuitry would be included in the unit itself, only that required to convert the current or voltage level in the unit to a RACU-compatible interface.

In this case, there would be no memory of any sort in the unit so that monitoring or level commands would have to be continually updated via the RACU at a rate commensurate with the time constants of the unit's circuitry. This could be accomplished directly by the DPA or indirectly by RACU programming controlled by the DPA. This would require mostly analog input

and output channels from the RACU as there are few devices which could interface directly with the digital or discrete RACU channels with no buffering.

Alternate B, on the other hand, would use the DPA facilities only for those functions involving significant data processing capability. The RACU would serve only as a communication interface with the DPA and as temporary storage for commands and responses at the convenience of the DPA and the ECA/ICA.

The ECA and ICA would perform the direct parameter monitoring and control; they would interpret communication configuration and mode commands from the DPA deciding which specific equipments should be interconnected to provide the requested capability. Similarly, monitored parameters would be processed and evaluated within the ECA and ICA and only go/no-go type of performance status would be reported to the DPA and preprocessed quantitative measurements would be reported for trend analysis.

These two approaches are reflected in the assignment of function responsibility for Alternates A and B in Table 3-14. Referring to the Alternate A and Alternate B columns, it can be seen that functions 1 and 2 which comprise the top level of control are assigned to the DPA in both instances. This is also true for functions 5, 6, 7, 14, 15, and 16 as these functions require significant programming and/or memory facilities.

Under Alternate A, there are only two functions (9 and 13) that are necessarily assigned to the ECA/ICA. The first, as it is the direct measurement of the physical quantities in the organic communication equipment and the second because of the limitations of the RACU channel characteristics (e. g., RF test signals) and because of the tailored design of these signals to the communication equipment being evaluated.

In constructing Alternate B, the first function to add is number 10, signal conditioning, to provide a better defined, local interface as it is always advantageous to develop standardized signals as close to their origination/termination point as possible.

Functions 11 and 12 would be added next as they are straightforward to implement with relatively simple circuitry and hardwire or PROM logic.

Functions 3, 4, and 8 are added which gives the ECA and ICA semi-autonomous operational capability while still under the complete control of the DPA.

3.3.4 Baseline Design

Alternates A and B define feasible limits of control design implementation; the baseline design lies between these limits and reflects additional factors that bear upon the ultimate realization of the desired performance objectives. For those functions where there is agreement between Alternates A and B, the baseline assignment is clear. Such is the case for functions 1, 2, 5, 6, 7, 9, 13, 14, 15, and 16.

TABLE 3-14. CONTROL DESIGN ALTERNATIVES

Function Ref. No.	Title	Alternate A		Alternate B		Baseline	
		DPA	ECA/ ICA	DPA	ECA/ ICA	DPA	ECA/ ICA
1	Configuration/mode selection	X		X		X	
2	Configuration command(s)	X		X		X	
3	Equipment selection	X			X		X
4	Implementation command(s)	X			X		X
5	Operational constraints	X		X		X	
6	Circuit performance status	X		X		X	
7	Equipment performance status	X		X		X	
8	Equipment availability	X			X		X
9	Parameter measurement		X		X		X
10	Signal conditioning	X			X		X
11	Limit level detection	X			X	X	
12	Parameter computations	X			X	X	
13	Test signal generation		X		X		X
14	Test program	X		X		X	
15	Fault isolation program	X		X		X	
16	Trend analysis	X		X		X	

It is recommended that functions 3, 4, and 8 also be included in the baseline at this time. These functions could be implemented on either side of the interface and, in the absence of any overriding consideration, would be assigned to the DPA to take advantage of its surplus capability. However, as these functions together provide the first level of decision control logic above the basic equipment, their inclusion within the ECA and ICA design responsibility will greatly facilitate a thorough consideration of the control/equipment design tradeoffs as the ECA and ICA designs evolve.

Function 10 is included in the baseline for the reasons given previously; the standardization of signal interfaces as close to their sources as possible. It is also felt that to assign this function to the DPA would require an excessive number of analog channels from the RACU. By providing relatively simple A/D and D/A conversion circuits within the ECA/ICA equipments, the more numerous discrete RACU channels can be used.

Functions 11 and 12 are assigned to the DPA as their design is more dependent on the design of the test and trend analysis programming than is the communication equipment. Therefore, it is considered better to assign the responsibility for their implementation to the DPA which also has the responsibility for these programming functions.

The resulting baseline control design provides a facility that, while always under the control of the DPA, still retains sufficient capability to be exercised relatively independent of the DPA. It avoids duplication of facilities by allocating those functions that require significant and flexible programming and mass memory to the DPA and at the same time provides a relatively clean interface between the DPA and the ECA/ICA.

It should also be mentioned that it may become apparent as the ECA and ICA designs evolve that memory or processing requirements for functions 3, 4, or 8 may be more efficiently provided by the DPA. This eventuality would not necessarily contradict assigning their design responsibility to the ECA/ICA at this time, however, as the critical design interface exists in the latter areas so these functions should be initially developed from the perspective of the communication equipment.

4. EXTERNAL COMMUNICATION ASSEMBLY DESIGN STUDIES

4.1 REQUIREMENTS

The ECA design requirements came from four sources:

1) Mission communication requirements

2) RF equipment baseline design developed by NAR/ITT

3) Control design requirements as developed during this study

4) Program requirements

The mission communication requirements are taken from Reference 2 and are summarized in Table 4-1. This gives the various combinations of communication services that are to be carried by the RF links shown. (These services are described in Table 4-2.) The data have been rearranged from that provided in the reference to illustrate the principal roles of the links. (Note that the mode numbers given here differ from those in the reference.) The primary communication circuits are the K band TDRS links which provide the highest capacity. The S band TDRS links are backups to the K band links and provide minimum, essential services. These links are given as S band here as it was agreed by the MSC technical monitor to substitute S band for the VHF service as given in the reference. This change was recommended when it was determined that sufficient capacity could be obtained using the MSS S band system provided for ground and shuttle links. This relieved the MSS of carrying the equipment for an additional frequency band to be used only as a backup. Additionally, it allowed the TDRS to concentrate its VHF capability on unmanned users.

The S band, MSS to ground links provide services similar to the K band link. Shown here are the service combinations that are unique to the S band link. The principal difference is the turnaround ranging which is originated by the ground and repeated by the MSS.

The MSS/shuttle links provide voice, data exchange, and ranging services associated with rendezvous, docking, and servicing of the shuttle vehicle.

The major design consideration to be observed from these requirements is the wide variety of different signal types and signal

TABLE 4-1. MISSION REQUIREMENTS

	Link→	I MSS→TDRS								II TDRS→MSS					III MSS→TDRS	IV TDRS→MSS	V MSS→GND			VI GND→MSS			VII MSS→SHUTTLE						VIII SHUTTLE→MSS					
Carrier Frequency	K Band→	X								X																								
	S Band→														X	X	X			X			X						X					
	Mode Number→	1	2	3	4	5	6	7	8	1	2	3	4	5	1	1	1	2	3	1	2	3	1	2	3	4	5	6	1	2	3	4	5	6
Communication Service	Voice (1 channel)														X	X							X	X	X				X	X	X			
	(3 channels)	X	X	X	X	X	X	X	X	X	X	X	X	X			X		X	X	X	X												
	Entertainment									X	X	X	X	X																				
	Color TV					X	X	X																										
	Facsimile		X				X					X																						
	Text and graphics												X							X														
	Control data									X				X		X					X											X	X	
	Systems data - 1			X				X	X																									
	Systems data - 2														X				X					X	X	X	X			X	X	X	X	
	Experiments data				X				X																									
	Turnaround ranging																X	X	X	X	X	X			X	X		X			X	X		X
	Computer data										X			X								X												

TABLE 4-2. COMMUNICATION SERVICE REQUIREMENTS

Service	Description	Bandwidth/ Data Rate
Voice	CCIR/CCITT quality; toll trunk compatible with inband supervisory signaling	300 to 3400 Hz
Entertainment	Commercial quality music/program material	10 kHz
Color TV	NTSC standard video plus 4.5 MHz aural subcarrier	4.5 MHz
Black and white TV	Restricted bandwidth without aural channel	2.9 MHz
Facsimile	Video signal representing hard copy material	500 kHz
Text and graphics	Digital representation of hard copy material	500 kbps
Control data	Digital command data	10 kbps
Systems data - 1	Digital telemetry data (high rate)	500 kbps
Systems data - 2	Digital telemetry data (medium rate)	50 kbps
Experiments data	Digital representation of scientific data	5 Mbps
Turnaround ranging	Pseudorandom code for range and range rate measurements	1 Mbps
Computer data	Digital representation of computer input/output	500 kbps

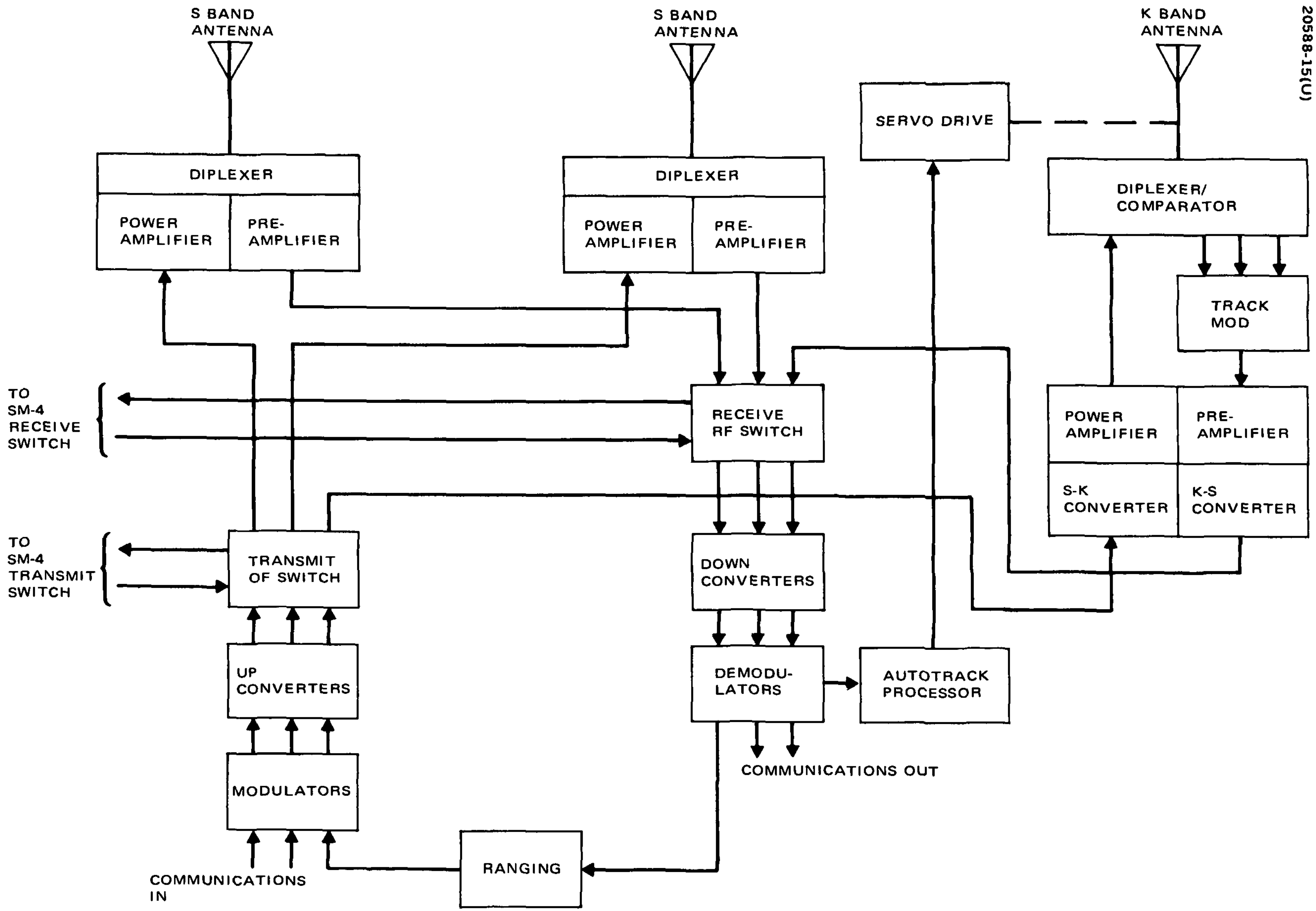


Figure 4-1. SM-1 External Communication Equipment

combinations that must be handled. Included here are narrow, medium, and wide band analog signals, and low rate, medium rate, and high rate digital signals, all originating from independent sources.

The electrical arrangement of the external communication equipment as developed by NAR/ITT is shown in Figure 4-1. This shows the equipment for one station module (SM-1); it is duplicated in the other station module (SM-4). The S band antennas are semidirectional mounted on opposite sides of the station module to give omnidirectional coverage; the high gain K band antenna is on a gimbaled mount to provide similar coverage.

The external communication equipment arrangement is a flexible, efficient configuration with transmitter power amplifiers and receiver preamplifiers collocated with their antennas to minimize power loss and system noise temperature degradation from connecting cables. It also has S band, low level switching to interconnect receiving and transmitting equipment in either station module to any of the antennas. The cross-connection of these duplicate sets of equipment at this point provides greater system reliability and additionally assures good antenna visibility for the multiple communication links.

The semidirectional (0 dB gain) S band antennas are used for all the links except the primary TDRS link. The latter employs one of the high gain directional K band antennas. If necessary (using the equipment of both station modules), it is possible to simultaneously provide duplex links to a shuttle, a detached research and applications module (DRAM), and conduct a handover with two ground stations and two relay satellites.

The control design requirements were developed during this study as described in Section 3.3. With respect to the ECA design, the control requirements dictate a considerable measure of flexibility in the arrangement of the baseband equipments that construct the composite baseband signal. It is necessary to be able to automatically establish new links with various signal combinations (modes) when instructed by the data processing assembly. Also, it must be possible to change modes on established links by command without disrupting the communications in process.

The self-test and monitoring control requirements impose a considerable degree of equipment command and parameter measurement capability to comprehensively monitor, test, and correct the complex communication equipments of the ECA. It is necessary to monitor and report sufficient parameters for the DPA to make a meaningful determination of ongoing circuit and equipment performance status and to detect deterioration. Special facilities must be provided to permit the on-line isolation of defective equipment to the line replaceable unit (LRU) level. All this must be accomplished via automatic control facilities in the ECA under the control of the DPA.

The design of the ECA proceeded from these requirements with guidance from the MSC technical monitor relative to program objectives. These objectives considered the further evolution and development of the design. It

was recognized that as the program proceeded many factors such as communication requirements, technology feasibility, and mission profiles would be modified from the present understanding. In order to readily accommodate these changes, the following design guidelines were deemed advisable:

1) Provisions should be made for flexible interconnection of equipment to permit addition, subtraction, or substitution of equipment types in the signal path.

2) Interfaces should be established about groups of equipment that shared a common technology and were functionally complete to the extent possible.

3) These interfaces should be simplified and use accepted standards.

4) Performance requirements should be feasible for existing technology.

Rule 1 would assure that as capacity requirements or signal designs changed quantities and types of units could be changed with minimal impact to other ECA units. Rules 2, 3, and 4 are principally directed at the problems of hardware development for systems feasibility and test. Rules 2 and 3 permit sections of the overall design to be designed and tested relatively independently of interfacing sections. Rule 4 assures that the overall ECA performance is not constrained by a single technology and that all portions of the design can be fabricated and tested to demonstrate feasibility and to test compatibility with other assemblies.

The following sections discuss the major design trades that were considered in the course of satisfying these requirements.

4.2 BASEBAND SIGNAL DESIGN

The first consideration to be addressed for the design of the ECA is the carrier modulation techniques to be employed in the various links. This was considered in the context of the RF systems analysis in Sections 3.1 and 3.2 The study concluded that, where maximum flexibility was desired and the link performance could support it, an FDM baseband was desirable. Conversely, where maximum efficiency was necessary and the signal format was fixed, a TDM baseband with direct carrier modulation was the best choice.

The K band TDRS link and the S band MSS to ground links are of the first category. Both links must provide for a wide variation of signal combinations and both have adequate performance margins. The backup S band TDRS link, on the other hand, has more limited performance capabilities, but its fixed signal format (only one mode) is amenable to a fixed signal design, hence time division multiplexing.

The MSS/shuttle links are the most difficult to satisfy. A flexible signal format is desired, but at the maximum range, the links cannot support the full requirements with an FDM signal design. This link differs from the others, however, as the range, and hence link performance, is not fixed. The conclusion reached in this study and reflected here is that the flexibility and proven reliability provided by the FDM baseband design outweighs the reduction in capability at the maximum range.

While these considerations determined the carrier modulator/demodulator designs to satisfy the designated requirements, additional capability was deemed desirable to provide for growth. Accordingly, a high rate direct-carrier modulation TDM capability was provided as an alternate mode for the K band MSS to TDRS link. It is felt that while an all-TDM design on this link is not the best approach at the present time, as the program evolves, the existence of this mode would encourage its use, and might eventually satisfy a majority of the requirements.

This is a desirable objective as a TDM format with digital carrier modulation promises significant improvements in link efficiencies with channel encoding. It also directs baseband signal designs toward digital formats that will make them substantially easier to handle, thus reducing the equipment complexity onboard the MSS.

To further encourage evolution of the design in this direction, it was decided to digitally encode the voice and entertainment services. This leaves only the television and facsimile in analog form and the latter could probably be readily converted, but there was insufficient information available about its characteristics to do so at this time.

In summary, FDM subcarrier channels were selected as the baseband format for the primary TDRS ground and shuttle links (I, II, V, VI, VII, and VIII) and TDM for the backup TDRS and the all digital TDRS links (links III, IV and link I, mode 8). These link signal formats are shown in Figure 4-2. Comparing this figure with Table 4-1, it can be observed that the subcarrier channels are shared by different services depending on the particular link mode. (See Section 3. 1 for the development of the channel bandwidth and spacing.) Thus the link can be reconfigured from mode to mode without disturbing the services in the other subcarrier channels.

4. 3 BASEBAND EQUIPMENT ARRANGEMENT

The main consideration in the arrangement of the baseband equipment is to provide flexibility. This is achieved by employing circuit switching fields at several stages of assembly of the baseband signal (Figure 2-3). These switches serve four purposes:

1) Permit the rearrangement of communication equipment for different link and mode configurations

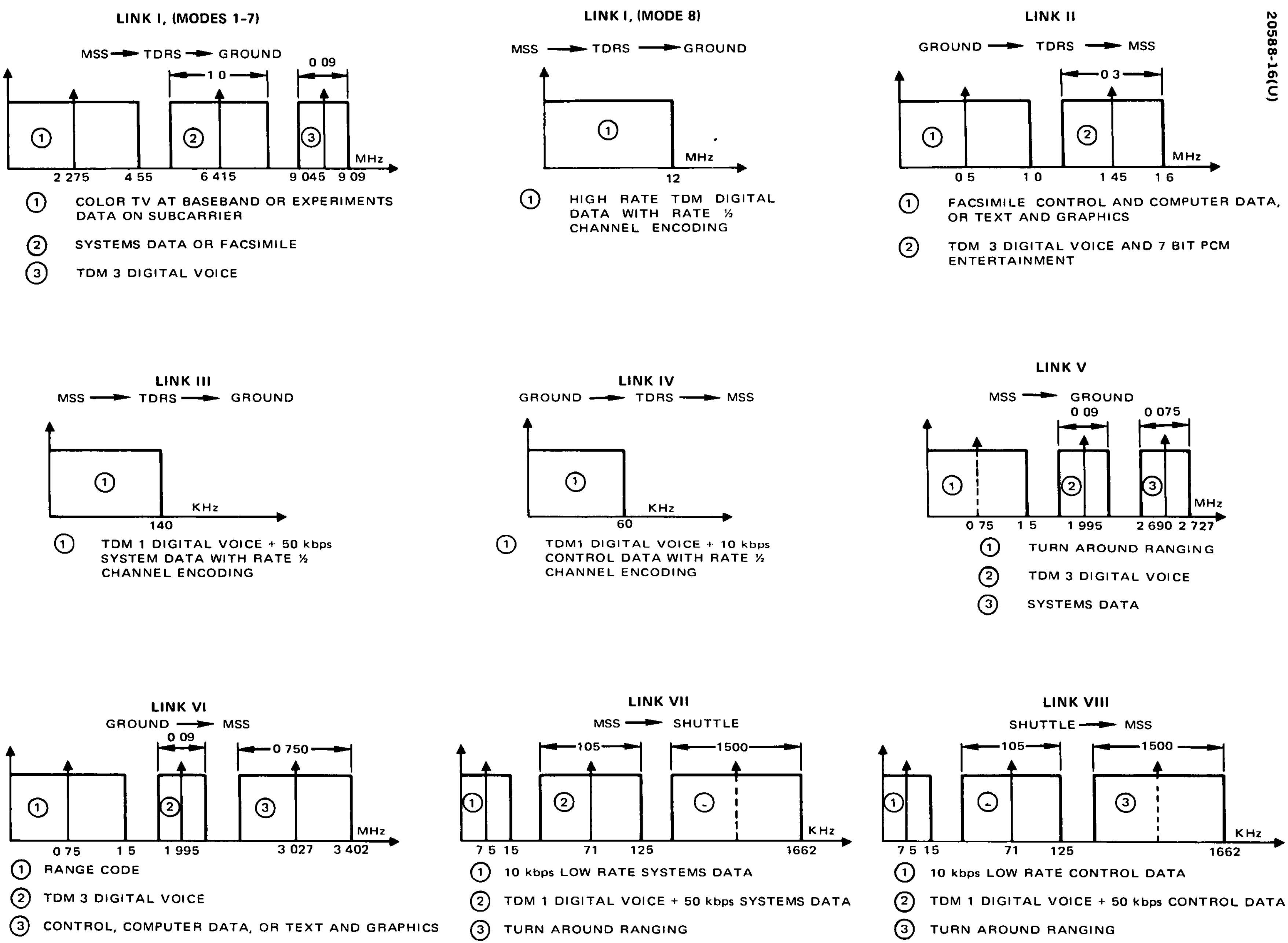


Figure 4-2. Baseband Signal Format

2) Increase system reliability by cross-strapping identical units

3) Permit the selective addition, deletion, or substitution of communication equipment without perturbing interfacing equipment

4) Facilitate loop testing for fault isolation

The next consideration was to form equipment groups and to determine the location of switching fields. This was done by reference to three criteria:

1) Equipments that share a common technology and have similar or complementary functions should be grouped together.

2) Serial elements should have dedicated (nonswitched) connections where there is a critical functional relationship and/or a complex circuit interface between the units.

3) Consistent with criteria 1 and 2, serial elements should have dedicated connections where the elements are highly reliable and of low weight and power consumption.

Referring to Figure 2-3, the first group formed at the input to the ECA combined the delta modulators/demodulators and digital-to-analog converters based on rule 1 above. Switching fields are provided at the input and output of this group for system reliability by cross-strapping (rather than additional redundant units) and also because the voice channels must be connected to all the different links at various times.

The digital multiplexers and demultiplexers and the channel encoders and decoders are combined in the TDM group because they share similar technology and complementary functions. Switching is not provided on the RF side of this group for several reasons. In the case of the encoded low rate channels it was because these are backup circuits for emergency use that justify the dedicated assignment of equipment to the function with a minimum of additional circuitry in the signal paths. On the other hand, the high rate channels are for growth and are in excess of present requirements, so they are minimally implemented. The low rate multiplexers and demultiplexers employed in the FDM modes and their associated modulators and demodulators are reliable, relatively simple units that permit their dedicated pairing.

Subcarrier modulators and demodulators, and carrier modulators and demodulators comprise two separate groups with switching between. The grouping is done on the basis of similar technology and complementary functions; the switching is provided for the assembly of baseband signals for different modes and for cross-strapping of subcarrier channels.

No switching is provided at the interface between the carrier modem group and the S band group as the upconverters and downconverters are simple, dependable units, and complete cross-strapping of all RF circuits is provided at the S band level.

All the S band RF equipment forms one group and the K band equipment a second. The ranging equipment has been included with the S band group since it is not a communication circuit function and its design is more nearly related to the S band RF characteristics than any of the baseband equipment. Similarly, the tracking receiver and antenna controller for the K band antenna are included in that group as their characteristics are tailored to the antenna, feed, and gimbal characteristics.

4.4 CONTROL GROUP DESIGN

The system trade studies (Section 3.3) considered the overall command and monitoring functions necessary for the DPA to control the ECA and ICA equipment and assigned responsibility for certain of these to each assembly control group. These were: 1) the selection of specific communication units from those available, 2) generation of controlling commands, 3) maintenance of equipment availability and status records in memory, 4) parameter measurement, 5) signal conditioning, and 6) test signal generation.

These requirements were to be met within the following design constraints:

1) The control design should be compatible with both ECA and ICA requirements.

2) The RACU is the two-way data interface with the DPA.

3) The design must be versatile to accommodate a wide variety of ECA and ICA equipment suits and physical installations.

4) It should be a reliable design with a minimum development risk.

5) It must be suitable for flight implementation.

In order to maximize versatility and serve both the ECA and ICA designs, it was decided to implement the control group as a digital multiplexed data system rather than as a single central unit that interfaced directly and in parallel with all ECA or ICA communication equipment. A multiplexed approach allows for reduction in weight because a common bus is substituted for the numerous interface lines from the control group to communication equipment. Also, it can be adjusted by programming to provide only the number of multiplexed input and output terminals required to meet the changing ECA and ICA requirements as they evolve, and it also permits economical use of analog-to-digital converters for signal conditioning.

Many communication equipment units of the ECA and ICA require adjustment of parameters for their operation. This function is provided by

the control group by means of serial digital outputs that were established to be similar to the serial digital outputs received from the DPA since they are used primarily to relay data from the DPA to the ECA or ICA equipment without alteration. The decision was made not to include a mandatory parity check on these data; if the presence of parity is judged essential to an individual unit, parity will be included in the data word from the DPA and checked by the receiving unit. This technique allows the entire transfer path to be checked, including the reception of the data by the communication equipment, and yet does not require a parity check in those applications where it is not needed. In cases where the control group generates the serial digital data (such as setting modulation indexes), parity is included in the command program and the data word is inserted in the bit stream from the DPA.

The communications between the central unit and the remote multiplexer/demultiplexer units is by Manchester-coded data. As this is a self-synchronizing code, it eliminates the problems of unequal time delays between separate clock and data lines and permits a more flexible physical arrangement of equipment.

The on/off control of communication equipment is achieved by means of pulse command outputs rather than level outputs. This is done because, if level outputs were used, a nonvolatile memory would have been required in the control group to store the status of all units during any power outages. With pulse command outputs, this storage function is included within those units of communication equipment that must come on in the same state after power outages, but need not be included in any equipment where this requirement is not present. The switches of the ECA and ICA, which operate under control of the control group, are also required to have nonvolatile memory of their configuration.

Parameter measurement and test signal generation responsibility was assigned to each communication equipment group as required. This was considered necessary to avoid a multiple line distribution and interference problem from a central location. It also was considered desirable to associate the development of this equipment with the communication units with which they are used to assure accurate, comprehensive test signal designs.

5. INTERNAL COMMUNICATION ASSEMBLY DESIGN STUDIES

5.1 REQUIREMENTS

The ICA design requirements are derived from three sources:

1) The equipment complement and performance developed by NAR/ITT (Reference 1)

2) Self-test and checkout philosophy and techniques developed by McDonnell Douglas (Reference 5)

3) Equipment design and performance analyses developed during this study

The specified ICA equipment complement and performance requirements are summarized in Tables 5-1 and 5-2, respectively. The self-test and checkout requirements for the ICA equipment are based largely on manual operations because of the difficulty of automating audio and visual performance evaluations. Some equipment circuit parameters are of interest, however, and the requirements for these are reflected in the control design discussed in Section 3.3.

The equipment design requirements derived during this study are intended to provide for the efficient, flexible operation of the ICA equipments and to facilitate the design development of these equipments on subsequent programs.

Thus, it was specified that the baseline design should provide general purpose interconnection capability using standard signal circuits that will allow maximum design flexibility. Such a capability should allow both the numbers and the types of interconnected equipment to be varied as may be required. The design should be flexible enough to allow interconnection of equipments of types other than those included in the baseline design when need for such equipment arises. Also, to simplify systems integration, both the numbers and the types of equipment interfaces should be minimized and standardized. Development of a small number of standard interfaces should be a design goal.

TABLE 5-1. MSS INTERNAL COMMUNICATION ASSEMBLY EQUIPMENT COMPLEMENT

Quantity	Equipment Type
2	Audio-video buses
12	Audio-video bus video channels
40	Audio-video bus medium rate channels
2	Paging-entertainment buses
4	Paging-entertainment bus channels
20	Audio video units
20	Modem units
30	Telephone sets
2	Telephone switchboards
2	TV cameras (black and white)
2	TV cameras (color)
9	TV monitors
4	Video recorders
4	Voice recorders
4	Music recorders
2	Music switches
4	Master paging-entertainment units
20	Remote paging-entertainment units
4	Video sync reference generators
4	FM modulators

To minimize and standardize interfaces, equipment should be organized into functionally integral groups that are capable of operating relatively independently of other equipment groups. This requirement reduces the number and complexity of problems encountered during systems integration. Moreover, it ensures that designers of each functional equipment group may independently test and evaluate their equipment with considerable freedom from the effects of other group designs.

It was also specified that design practices for common communication equipment should be those employed for similar terrestrial equipment. This requirement permits the convenient use of well-understood standards and techniques.

5.2 EQUIPMENT ARRANGEMENT

Consideration of the functional and design requirements leads to the formation of six equipment groups within the ECA. Each is functionally integral and employs common technology. They are:

1) Voice communication group

2) Video communication group

TABLE 5-2. MSS ICA PERFORMANCE REQUIREMENTS

1) Audio-Video Communications

- Full duplex voice, caution and warning signals, public address, and closed-circuit video communications available in all habitable space station areas
- Voice communications to provide telephone type voice communications, both private and conference, both internal and external to station
- Capability to record and playback voice and video signals
- Capability to provide both color and black and white closed-circuit television
- Internal communications neither interrupted nor degraded due to malfunction of equipments within one pressure volume

2) Entertainment

- Capability to receive selectable audio and video entertainment in selected station areas
- Entertainment and paging available in all habitable modules
- Capability to override music entertainment with paging or audio alarm independent of volume control
- Capability to play back prerecorded music and video signals
- Capability to record from external communication music link

3) Control

- Override telephone access to critical areas by station commander with automatic telephone number code generation and termination of any calls in progress
- Primary control of intercommunications from control areas
- Provide subsystem status data to DPA

3) Music entertainment group

4) Audio-video bus group

5) Paging entertainment bus group

6) Control group

The voice communication group is composed of telephone sets and a central telephone switchboard that operates in a manner similar to a conventional CENTREX system. The video communication group provides essentially a small-scale closed-circuit TV system. It is composed of TV cameras, TV monitors, and video recorders that, although designed especially for this application, are functionally identical to their broadcast industry equivalents. The music entertainment group provides a station public address and closed-circuit entertainment network of conventional design.

The audio-video bus group provides interconnection for the voice and video communication groups equipment, as does the paging entertainment bus group for the music entertainment group. The control group commands and monitors all the ICA equipment under the control of the DPA.

The first three groups presented no design trades within themselves as they were clearly defined in the requirements and conventional implementation of these functions is appropriate and desirable. Also, the NAR/ITT studies recommended that a hardwire intercom facility, which is installed for use during the station buildup period, be used for the paging-entertainment bus. That appears to be an adequate solution and is accepted for the baseline.

The audio-video bus group and the control group, however, presented significant design considerations. These are discussed in the following sections.

5.3 AUDIO-VIDEO BUS DESIGN

The audio-video bus and associated AVUs are used to interconnect various telephone, entertainment and video equipments. The design considerations posed by this group were:

1) How many and what type of audio and video units to serve

2) Dedicated or variable channel assignment

3) Multiple access techniques

The first consideration concerns whether all audio and video units should be accessed by the bus or only physically remote units with the others connected by dedicated, hardwire lines. If most units are within proximity

of each other, hardwire dedicated lines would not impose a severe weight penalty. On the other hand, if a significant number of the units are dispersed from the rest and/or need to be relocated, more flexibility is provided by accessing all units through a common facility.

Channel assignment, whether dedicated or variable, has several implications. Dedicated assignment requires less control sophistication and so is inherently more reliable. It has limitations, however, as the assignment must be fixed accurately before designed if it is to be at all efficient. In an evolving program where this is not feasible, the bus requirements could become severe if sufficient excess capacity is built in to allow for normal changes.

Also, fixed assignments provide duplex circuits between two points only; external switching must be provided for random interconnection of units. For the telephone service, this is no burden as a switchboard is the usual and best way to do the switching. For the video circuits, however, which do not require the automatic supervisory services of the telephone network, a variable assignment design could also serve the switching function.

The selection of the multiple access technique depends on the previous consideration and equipment performance assessments.

To illustrate the trades inherent in these considerations, two alternative designs were posed. Alternate A is the simplest, it uses the bus only for physically remote equipment and has dedicated assignments. Alternate B takes the opposite approach; all units connect via the audio-video bus and it uses variable assignments. The design trades for these two alternatives are summarized in Table 5-3.

The most significant difference between the two alternatives is their relative design flexibility. Alternative A is essentially a fixed design, where Alternate B has complete flexibility within large variances.

The interfaces between the audio-video group and the other equipment groups also are quite different for the two cases. Alternate A requires careful attention to electromagnetic interference control because of the large number of hardwire lines that will be harnessed together where the equipment is concentrated in the station modules. Alternate A would be difficult to test for this reason also, since it will be composed of a wide variety of different signals on many parallel circuits that severely compromises the design objective for functional integrity.

Alternate B requires significantly more complexity in the design of the AVUs. The flexibility it offers is achieved only through more sophisticated input/output processing and control facilities.

TABLE 5-3. AUDIO-VIDEO BUS GROUP DESIGN TRADES

Design Characteristics	Alternate A	Alternate B
Design flexibility	1. Equipments constrained to central location 2. Equipment numbers and types relatively fixed once interconnection design determined 3. Network connections limited	1. Complete freedom in locating equipment 2. Equipment complement easily modified 3. Network connections easily modified
Group interface characteristics	1. Small number of different bus interfaces 2. Large number of different hardwire interfaces	1. Large number of standardized bus interfaces
Functional integrity	Poor; requires many different input/output signal simulators to test	Good; requires few standard signal simulators
Equipment complexity	1. Low risk AVUs 2. Low risk bus if no significant growth capacity required 3. Requires video switch	1. Moderate complexity in AVUs 2. Low risk bus

The bus design will be low risk in both instances because the variable assignment feature of Alternate B allows it to serve many more audio video units with about the same number of channels as Alternate A. If the bus capacity requirements of Alternate A are increased, however, to provide for more stations and/or some freedom to relocate them, the bus design for Alternate A may become much more difficult.

In view of these considerations, Alternate B was selected for the baseline design. Also, to minimize the development risk associated with this choice, frequency division multiple access with one video channel per carrier was

chosen as the multiple access technique for the video channels. This is commonly employed on cable television systems and gives highly reliable service.

For the control and voice channel service, single sideband FDM is used. The voice channels are combined into 12 channel groups and inserted in an upright, single-sideband carrier group. Carrier and sidetones are provided for modulation and demodulation references.

5.4 CONTROL EQUIPMENT DESIGN

The control equipment provided for the ECA readily satisfies the group control requirements of the ICA. The variable assignment audio-video bus design, however, requires additional control facilities beyond those at the group level.

These could be satisfied by providing a control group remote multiplexer/demultiplexer at each AVU or, alternatively, one could be provided at a central point of the audio video bus group and dissemination of commands from this point to all AVUs could be accomplished over the bus.

Providing remote multiplexers/demultiplexers at each AVU would simplify their design by removing any logical processing. For remote units, however, this would require either that the ICA control group data link be extended throughout the MSS to all remote camera locations or that the digital data bus be used and RACUs be provided along with each AVU.

Also, if the control group commands each AVU directly, the functional integrity of the audio-video bus group is destroyed since it could only be thoroughly evaluated when paralleled by the control group equipment.

For these reasons, it was decided to keep the AVU command distribution function integral to the audio-video bus control group. These commands are transmitted to the audio-video control group baseband compiler along with AVU address codes. The baseband compiler is programmed to associate these address codes with control channel frequency assignments for each AVU and modulates and inserts the command in the appropriate slot.

Monitored parameters from each AVU similarly are received by the baseband compiler and outputted to its remote multiplexer/demultiplexer.

6. REFERENCES

1. "MSS Plan B Extension, Preliminary System Design," Vol. IV Subsystem Analyses, NAR Space Division, SD 71-217-4, January 1972.

2. H. R. Rosenberg, "MSS External Communications System Design," NASA MSC, EE-72-8012, March 1972.

3. R. J. Westcott, "Investigation of Multiple FM/FDM Carriers Through a Satellite TWT Operating Near to Saturation," Proceedings IEE, Vol. 114, No. 6, June 1967.

4. "TDRSS Interim Part I Review," Hughes Aircraft Co., HS337-0093, 7 July 1972.

5. "Final Report Communications Systems Checkout Study," McDonnell Douglas Astronautics Co., MDC G2909, March 1972.

APPENDIX A. DERIVATION OF SIGNAL-TO-NOISE RATIOS FOR MULTIPLE BASEBAND CHANNEL FM AND PM MODULATION

An angle-modulated carrier with sinusoidal modulation may be represented as:

$$y(t) = A_c \cos \left[\omega_c t + \beta \cos (\omega_m t)\right] \tag{1}$$

where

$$\beta = \text{peak phase deviation for PM} \tag{2}$$

$$\beta = \frac{\Delta\omega}{\omega_m} \quad \text{for FM}$$

The peak frequency deviation for PM is the magnitude of the derivative of the phase of Equation 1:

$$(\Delta\omega)_{PM} = \left|\frac{d}{dt} \beta \cos \omega_m t\right| = \beta\omega_m$$

$$(\Delta f)_{PM} = \beta f_m \tag{3}$$

It is desired to determine the subcarrier signal-to-noise and the carrier-to-noise relationship for the generalized baseband configuration of Figure A-1.

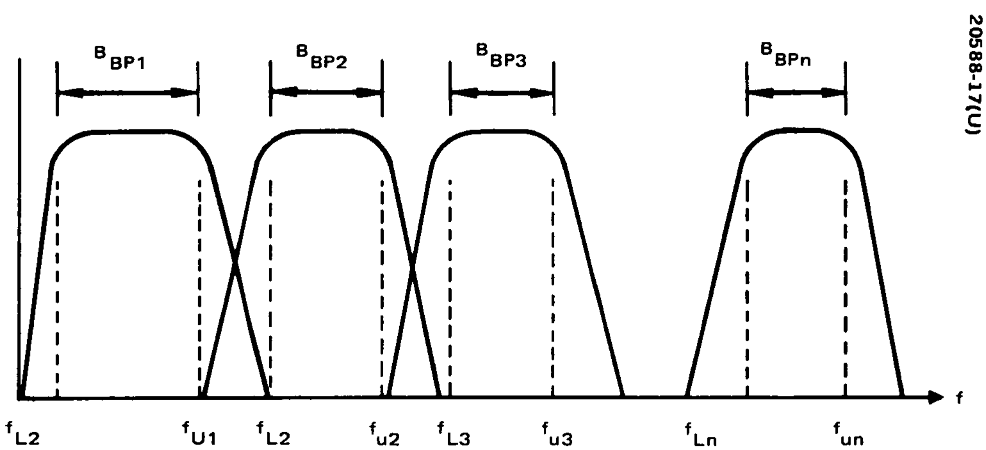


Figure A-1. Subcarrier Channel Baseband

FM SNR

The signal power at the output of the FM detector is

$$S = \frac{b^2}{2} \beta^2 \omega_m^{\ 2} \tag{4}$$

where b is the detector constant.

The noise power density is

$$dN = \frac{b^2}{A_c^{\ 2}} N_o \omega^2 df \tag{5}$$

where N_o is the noise spectral density at the IF output.

The noise power is obtained by integrating Equation 5 over the band-pass channel limits:

$$N = \frac{b^2}{A_c^{\ 2}} N_o (2\pi)^2 \left[\int_{-f_u}^{f_1} f^2 \, df + \int_{f_1}^{f_u} f^2 \, dt \right]$$

$$N = \frac{2}{3} \frac{b^2}{A_c^{\ 2}} N_o (2\pi)^2 \left(f_u^{\ 3} - f_1^{\ 3} \right) \tag{6}$$

The signal-to-noise ratio is obtained from Equations 4 and 6:

$$\frac{S}{N} = \frac{3\beta^2 f_m^{\ 2} A_c^{\ 2}}{4N_o \left(f_u^{\ 3} - f_1^{\ 3} \right)}$$

Multiplying by B_{RF}/B_{RF}:

$$\frac{S}{N} = \frac{3}{2}\beta^2 \cdot \frac{B_{RF}}{B_{BP}} \cdot \frac{C}{N} \tag{7}$$

where

$$C = A_c^{\,2}/2$$

$$B_{BP} = f_u - f_l$$

$$f_m^{\,2} \triangleq f_u^2 + f_u f_l + f_l^2$$

PM SNR

The signal power at the output of the phase detector is:

$$S = \frac{b^2}{2}\beta^2 \tag{8}$$

where b is the detector constant.

The noise power density is

$$dN = \frac{b^2}{A_c^{\,2}} N_o \, df \tag{9}$$

The noise power is obtained by integrating Equation 9 over the band-pass channel limits:

$$N = \frac{b^2}{A_c^{\,2}} N_o \left[\int_{-f_u}^{-f_l} df + \int_{f_l}^{f_u} df \right]$$

$$N = \frac{2\, b^2 N_o}{A_c^{\,2}} \left(f_u - f_l\right) \tag{10}$$

The signal-to-noise ratio is obtained from Equations 8 and 10:

$$\frac{S}{N} = \frac{\beta^2 A_c^{\,2}}{4N_o\left(f_u - f_l\right)}$$

Multiplying by B_{RF}/B_{RF} gives:

$$\frac{S}{N} = \frac{\beta^2}{2} \cdot \frac{B_{RF}}{B_{BP}} \cdot \frac{C}{N} \tag{11}$$

where

$$C = A_c^{\,2}/2$$

$$B_{BP} = f_u - f_l$$

RF BANDWIDTH

The RF bandwidth (B_{RF}) required to pass the carrier spectrum of Figure A-1 depends on the characteristics of the signals in the subchannels and how the carrier deviations from each signal combine.

For sinusoidal modulation, a conservative assumption is to use the maximum carrier deviation as:

$$\Delta f_{max} = \Delta f_1 + \Delta f_2 \ldots + \Delta f_n$$

For both FM and PM, using relations 2 and 3,

$$\Delta f_{max} = \beta_1 f_{m1} + \beta_2 f_{m2} \cdots + \beta_n f_{mn}$$

The corresponding Carson's Rule bandwidth is:

$$B_{RF} = 2 \quad \beta_1\left[f_{m1} + \beta_2 f_{m2} \cdots + \left(\beta_n + 1\right) f_{mn}\right]$$

Taking the conservative approach f_m is taken here as the highest passband frequency, f_u:

$$B_{RF} = 2 \left[\beta_1 f_{u1} + \beta_2 f_{u2} \cdots + \left(\beta_n + 1\right) f_{un}\right] \tag{12}$$

Notice that for the FM case, β is determined by Equation 2 and the definition of f_m in Equation 7. For PM, β is independent of f_m.

APPENDIX B. DERIVATION OF CARRIER-TO-NOISE RATIO ON TANDEM RF LINKS

An RF circuit through a linear satellite repeater may be represented as in Figure B-1. P_u is the uplink signal power as received at the spacecraft repeater and N_s is the repeater and antenna noise power at the same point. P_d is the maximum linear power output of the repeater as received at the downlink receiver (e.g., a ground station) and N_g is the downlink receiver antenna and receiver noise power.

The separate uplink and downlink (CNR)s are:

$$(CNR)_u = \frac{P_u}{N_s} \tag{1}$$

$$(CNR)_d = \frac{P_d}{N_g} \tag{2}$$

The output power at the downlink receiver P_o is the sum of P_d and N_g. P_d, however, is shared linearly between the uplink signal and uplink noise, so that P_o may be written as:

$$P_o = \frac{Pu}{Pu + N_s} P_d + \frac{N_s}{P_u + N_s} P_d + N_g \tag{3}$$

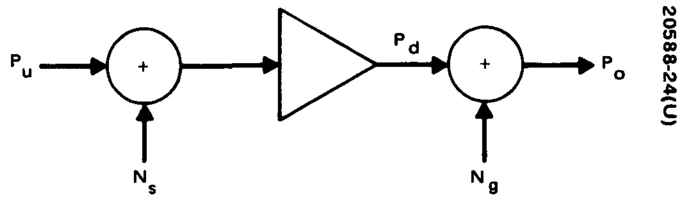


Figure B-1. Tandem RF Link Notation

The first term on the right-hand side of Equation 3 represents the repeated uplink signal and the second term the repeated uplink noise. The $(CNR)_g$ is the ratio of the first term to the sum of the second and third terms:

$$(CNR)_g = \frac{\frac{Pu}{P_u + N_s} P_d}{\frac{N_s}{P_u + N_s} P_d + N_g}$$

This can be rearranged to be:

$$(CNR)_g = \frac{\frac{Pu}{N_s} \bullet \frac{P_d}{N_g}}{\frac{Pu}{N_s} + \frac{P_d}{N_g} + 1} \tag{4}$$

Substituting Equations 1 and 2

$$(CNR)_g = \frac{(CNR)_u \; (CNR)_d}{(CNR)_u + (CNR)_o + 1} \tag{5}$$

In the previous analysis, the bandwidths of the spacecraft repeater and the ground receiver were ignored (implicitly assumed to be matched to each other and the signal bandwidth). This is the optimum arrangement and can be closely realized with stationary spacecraft, ground-based receivers and signal bandwidths that are reasonable percentages of the carrier frequencies. There are applications where these conditions do not pertain, however, and it is of interest to develop the expression for this latter case.

The noise powers N_s and N_g can be expanded as:

$$N_s = k \; T_r \; B_r \tag{6}$$

$$N_g = k \; T_g \; B_g \tag{7}$$

where T_r and T_g are the system noise temperatures of the repeater and ground receivers, respectively, and B_r and B_g are the noise bandwidths.

Substituting Equations 6 and 7 in Equation 4 gives

$$(CNR)_g = \frac{\frac{Pu}{k\,T_r\,B_r} \bullet \frac{P_d}{k\,T_g\,B_g}}{\frac{Pu}{k\,T_r\,B_r} + \frac{P_d}{k\,T_g\,B_g} + 1} \tag{8}$$

which can be rewritten as:

$$(CNR)_g = \frac{\frac{K_u}{B_r} \cdot \frac{K_d}{B_g}}{\frac{K_u}{B_r} + \frac{K_d}{B_g} + 1} \tag{9}$$

where

$K_u = Pu/kT_r$

$K_d = P_d/kT_g$

Two parameters may be introduced which relate the repeater and downlink receiver bandwidths to the signal bandwidths (B_{rf}):

$$\delta_r = \frac{B_r}{B_{rf}} \quad , \quad \delta_g = \frac{B_g}{B_{rf}}$$

for $\delta_r \geq \delta_g \geq 1$

With these substitutions for B_r and B_g, Equation 9 becomes:

$$(CNR)_g = \frac{K_u K_d}{\delta_g K_u + \delta_r K_d + \delta_r \delta_g B_{rf}} \tag{10}$$

For a downlink receiver which tracks the carrier δ_g may be made arbitrarily close to 1 so that Equation 10 becomes:

$$(CNR)_g = \frac{K_d \theta}{\delta_r + \theta} \quad ; \quad \theta = \frac{K_u}{K_d + B_{rf}} \tag{11}$$

To observe the degradation from the optimum case where all bandwidths are matched ($\delta_r = 1$),

$$\Delta_{CNR} = \frac{\dfrac{K_d \theta}{\delta_r + \theta}}{\dfrac{K_d \theta}{1+\theta}} = \frac{1 + \theta}{\delta_r + \theta} \tag{12}$$

This can be evaluated readily for two extremes, the uplink limited and downlink limited situations. That is:

<u>Uplink limited</u>: $(CNR)_d \geq 10\ (CNR)_u$

$$\theta = \frac{(CNR)_u}{(CNR)_d + 1} \approx 0.1$$

<u>Downlink limited</u>: $(CNR)_u \geq 10\ (CNR)_d$

$$\theta \approx 10$$

and Equation 12 becomes for the two cases:

$$\Delta_{CNR} \approx \frac{1.1}{\delta_r + 0.1} \quad \text{(uplink limited)} \tag{13}$$

$$\Delta_{CNR} \approx \frac{11}{\delta_r + 10} \quad \text{(downlink limited)}$$

For balanced (CNR)s at threshold $[(CNR)_u = (CNR)_d = 8.46]$ (12) becomes:

$$\Delta_{CNR} = \frac{1.894}{\delta_r + 0.894} \tag{14}$$

VOLUME II

MODULAR SPACE STATION

EXTERNAL COMMUNICATION AND INTERNAL COMMUNICATION ASSEMBLIES PERFORMANCE AND INTERFACE SPECIFICATION

Volume II

CONTENTS

ILLUSTRATIONS

TABLES

1.0 SCOPE

1.1 Objective

The purpose of this specification is to establish the performance and interface requirements for the external communication and internal communication assemblies of the modular space station based on the designs described in Volume I of this report.

Functional descriptions of these designs are provided in Sections 2.0 (ECA) and 4.0 (ICA).

A major objective in this initial effort was to identify critical performance parameters and tolerances. This has been done in the electrical interface specifications (Sections 3.0 and 5.0) by stating key parameters and assigning typical values. These values, while representative, will need to be refined and expanded as the system design evolves.

1.2 Related Documentation

The following documents provide background and system design requirements for equipment described in this specification.

Publication		Title
NASA/MSC EE-72-8012 March 1972		Modular Space Station External Communications System Design.
NAR/SD - SD 71-217-4 January 1972		MSS Preliminary System Design. Vol. IV, Subsystems Analysis
TRW Systems Group December 3, 1971	- DRL No. 9 - DRD No. SE-173T - NAS 9-12185	RACU Design Performance Specification
HAC/S&CG July 7, 1972	- SCG 20413B	TDRSS Interim Part I Review
MDAC March 1972	- DRL No. T-675 - ORD No. SE 2717	Communications Systems Checkout Study Final Report
HAC/S&CG August 1972	- SCG 20588R	Parametric Analysis of RF Communications and Tracking Systems - Final Report. Vol. I, System Analysis and Baseline Design

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2.0 EXTERNAL COMMUNICATION ASSEMBLY FUNCTIONAL CHARACTERISTICS

2.1 S Band Group

The S band group for each of the two station modules, SM-1 and SM-4, consists of nine upconverters, nine downconverters, two RF switches, two power amplifiers, two preamplifiers, two diplexers, two S band antennas, and ranging equipment. The arrangement and employment of these equipments, as described in this specification, were developed by NAR/ITT on prior MSS system studies. Figures 1 and 2 show the electrical and physical arrangements, respectively. For a detailed description of these equipments, refer to the system study documentation listed in Section 1.2. A brief description of the functional characteristics of each equipment type follows.

2.1.1 Upconverters

The upconverters translate the outputs of the carrier modulators in the carrier modem group from intermediate frequencies to S band frequencies. The upconverters are used for both K band link and S band link signals. The local oscillator frequency of each upconverter is selectable by command from the control group.

2.1.2 Downconverters

The downconverters translate S band link and K band link signals from S band frequencies to intermediate frequencies. Seven downconverters drive carrier demodulators in the carrier modem group and two provide inputs to tracking receivers in the K band group. The local oscillator frequency of each downconverter is selectable by command from the control group.

2.1.3 RF Switches

The transmit and receive RF switches, located on the MSS structure as shown in Figure 2, operate at S band frequencies. The transmit switch provides an interconnection matrix between the upconverter outputs and the S band group power amplifiers and the K band group S-K converters. The receive switch interconnects the S band group preamplifier outputs and the K band group K-S converter outputs to the downconverters. Both transmit and receive switches are interconnected with their duplicate counterparts as shown in Figure 2 to permit cross-connection of the two. Specific interconnections are determined by control group commands. The RF switch configuration data are provided as an output for periodic sampling by the control group.

2.1.4 Power Amplifiers

The S band power amplifiers amplify the S band signals from the RF switch to a nominal 14.8 dBw for radiation by the S band antennas.

2.1.5 Preamplifiers

The S band preamplifiers amplify the S band signals received by the S band antennas and provide a nominal 500°K system noise temperature.

2.1.6 Diplexers

The diplexers provide necessary isolation at the interface between the S band antennas and the power amplifiers and preamplifiers.

2.1.7 S Band Antennas

The S band antennas are semidirectional providing 0 dB gain.

2.1.8 Ranging Equipment

The ranging equipment includes ranging receivers, range code generators, biphase modulators, and other ancillary equipment as required to provide turnaround ranging to the ground, and to originate or turn around ranging signals with the shuttle.

The operational ranging equipment interfaces are external to the ECA. No provision is made for outputting range and range rate data or inputting range code instructions. These are considered to be processed directly between the ranging equipment and the DPA via a dedicated RACU interface.

The ranging equipment interfaces with the ECA are comprised of subcarrier inputs and outputs to the carrier modulators and demodulators and normal equipment command and monitoring functions.

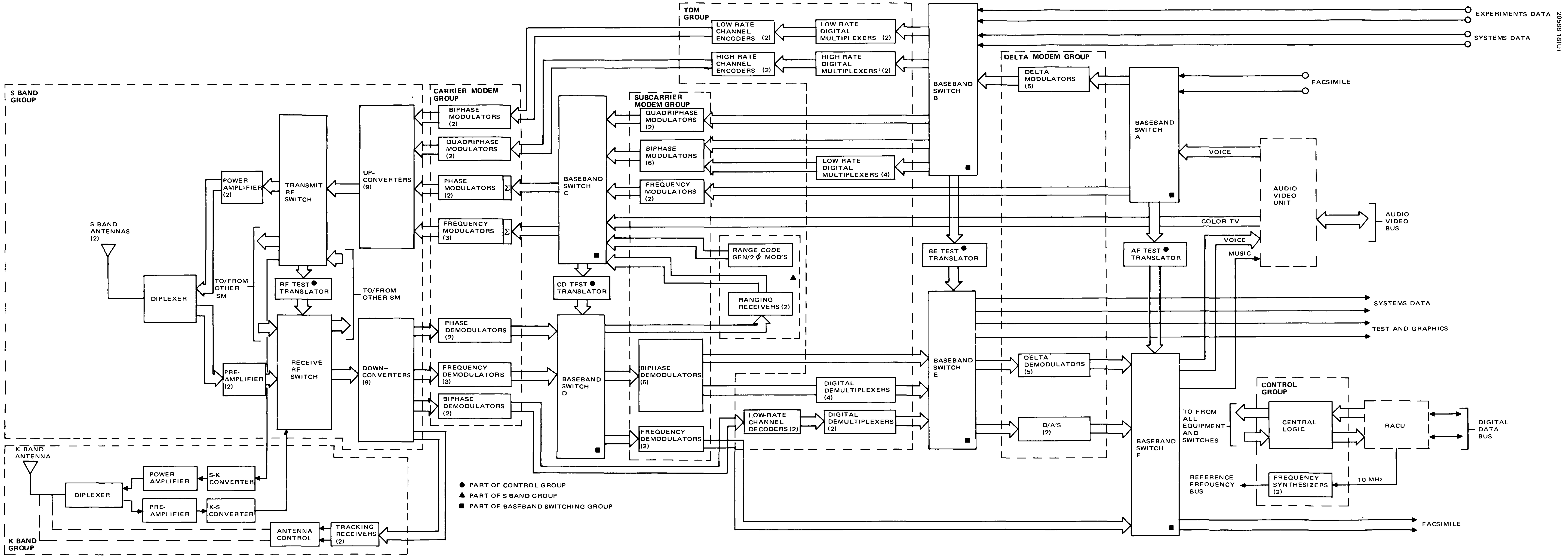

Figure 1. ECA Block Diagram

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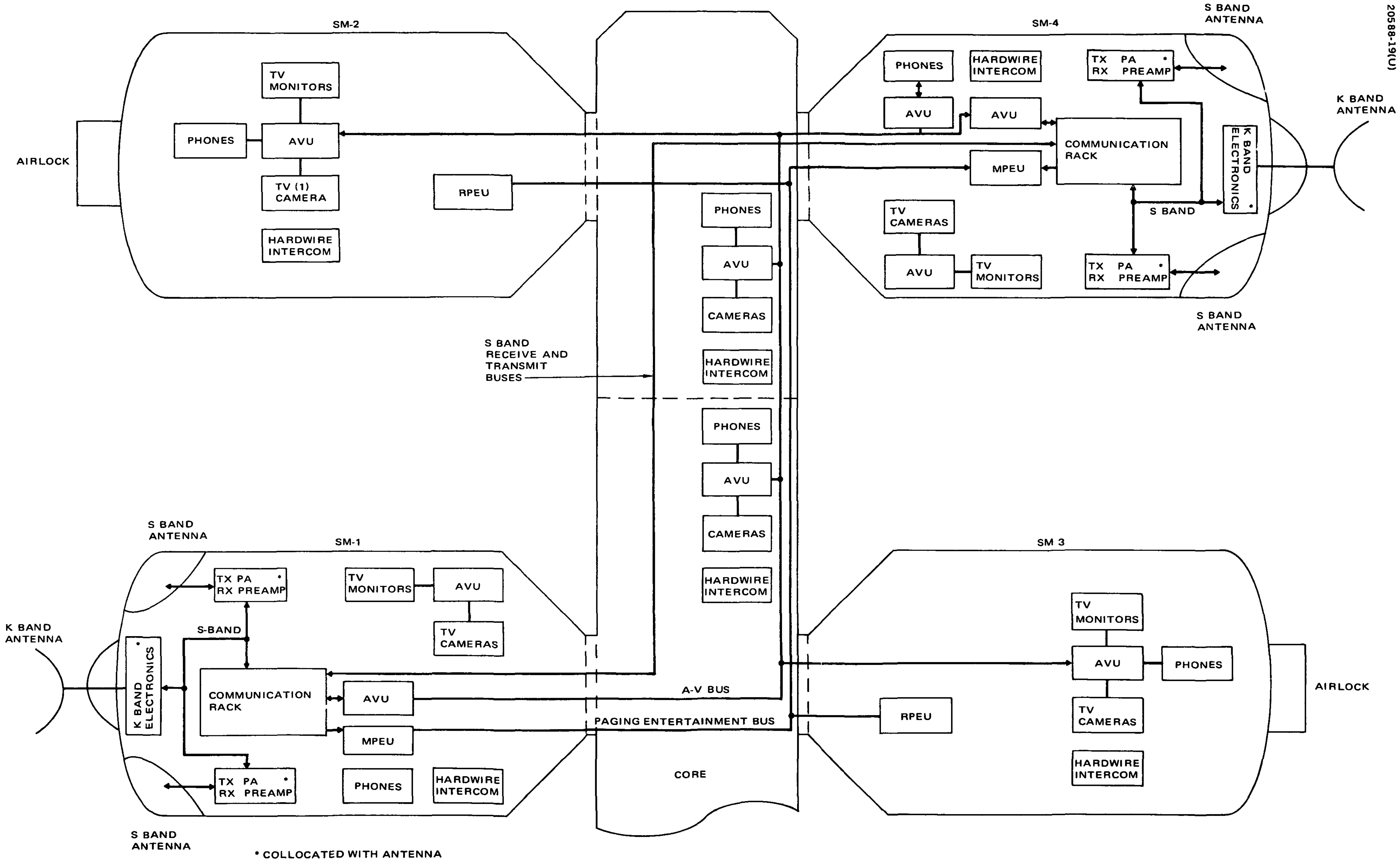

Figure 2. MSS Communication Assemblies Physical Arrangement

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2.1.9 Control and Monitoring

The S band equipment group responds to the control group commands listed in Table I and provides the signal outputs listed in Table II for periodic monitoring by the control group.

TABLE I. S BAND GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1	Pulse	Upconverter A - On
2	Pulse	Upconverter A - Off
3-18	Pulse	Upconverters - On and Off
19-36	Pulse	Downconverters - On and Off
37-40	Pulse	Power amplifiers - On and Off
41-44	Pulse	Preamplifiers - On and Off
45-48	Pulse	Ranging Receivers - On and Off
49-52	Pulse	Ranging code gen/biphase modulator - On and Off
53-61	Serial	Upconverter local oscillator frequencies
62-70	Serial	Downconverter local oscillator frequencies
71-72	Serial	RF switch configuration
52	Pulse	Total
20	Serial	

TABLE II. S BAND GROUP MONITORED PARAMETERS

Signal Number	Signal Type	Signal Monitored
1	Bilevel	Upconverter A - On/Off
2-10	Bilevel	Upconverters - On/Off
11-18	Bilevel	Downconverters - On/Off
19-20	Bilevel	Power amplifiers - On/Off
21-22	Bilevel	Preamplifiers - On/Off
23-24	Bilevel	Ranging receivers - On/Off
25-26	Bilevel	Range code gen/biphase modulator - On/Off
27-98	Bilevel	Upconverters (8 parallel bilevel bits each)
99-170	Bilevel	Downconverters (8 parallel bilevel bits each)
171-186	Bilevel	Power amplifiers (8 parallel bilevel bits each)
187-202	Bilevel	Preamplifiers (8 parallel bilevel bits each)
203-229	Analog	Upconverters (3 each)
230-256	Analog	Downconverters (3 each)
257-268	Analog	Power amplifiers (3 each)
279-280	Analog	Preamplifiers (3 each)
281-290	Analog	Ranging equipment
202	Bilevel	Total
88	Analog	

2.2 K Band Group

The K band group for each of the two station modules, SM-1 and SM-4, consists of one S-K and one K-S converter, a K band power amplifier, a K band preamplifier, a diplexer and directional K band antenna, tracking receivers, and antenna controllers. The arrangement and employment of these equipments as described in this specification were developed by NAR/ITT on prior MSS system studies. For a detailed description of these equipments, refer to the system study documentation listed in Section 1.2. A brief description of the functional characteristics of each equipment type follows.

2.2.1 S-K Converter

The S-K converter translates the K band link transmit signals from the output of the transmit RF switch to the appropriate K band frequency. This equipment is located adjacent to the K band antenna on the station module.

2.2.2 K-S Converter

The K-S converter translates the K band link signal received from the TDRS to an appropriate S band signal at the receive RF switch interface. This equipment is located adjacent to the K band antenna on the station module.

2.2.3 K Band Power Amplifier

Cross-connected, parallel K band power amplifiers are provided with a combined nominal output of 14 dBw reducing to 7.9 dBw in the event of the failure of either unit. This equipment is located adjacent to the K band antenna on the station module.

2.2.4 K Band Preamplifier

A low noise, TDA preamplifier provides a nominal system temperature of 800°K. Commandable gain control is provided via the control group. This equipment is located adjacent to the K band antenna on the station module.

2.2.5 K Band Antenna and Diplexer

A high gain, directional K band antenna and diplexer are mounted on the station module. The nominal gain is 44.5 dB. The positioning of this antenna is provided by controls from the antenna control equipment. The positioning signals are considered to be provided via a dedicated RACU interface and are not considered as part of the ECA interfaces.

Normal equipment command and monitoring are provided by the control group.

2.2.6 Tracking Receiver and Antenna Control Equipment

Tracking receivers and antenna control equipment are provided for automatic tracking and/or programmed tracking as required. The operational signal interfaces between the tracking receivers and antenna control equipment, the antenna servo drivers, and the DPA are considered external to the ECA and provided by dedicated RACU interfaces.

The tracking receivers are provided an IF interface at the output of the downconverters and normal equipment command and monitoring functions are provided by the ECA control group.

2.2.7 Control and Monitoring

The K band equipment is controlled and monitored by the ECA control group. The control commands are listed in Table III and an estimate of the monitored parameters is given in Table IV.

TABLE III. K BAND GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1	Pulse	S-K converter - On
2	Pulse	S-K converter - Off
3-4	Pulse	K-S converter - On and Off
4-5	Pulse	Power amplifier - On and Off
5-7	Pulse	Preamplifier - On and Off
8-11	Pulse	Tracking receivers - On and Off
12-15	Pulse	Antenna controllers - On and Off
16	Serial	Power amplifier level
17	Serial	Preamplifier gain
18	Serial	Tracking receivers
19	Serial	Antenna controllers
15	Pulse	Total
4	Serial	

TABLE IV. K BAND GROUP MONITORED PARAMETERS

Signal Number	Signal Type	Signal Monitored
1	Bilevel	S-K converter - On/Off
2	Bilevel	K-S converter - On/Off
3	Bilevel	Power amplifier - On/Off
4	Bilevel	Preamplifier - On/Off
5-6	Bilevel	Tracking receivers - On/Off
7-8	Bilevel	Antenna controllers - On/Off
9-16	Bilevel	S-K converter (8 parallel bits)

TABLE IV (continued)

Signal Number	Signal Type	Signal Monitored
17-24	Bilevel	K-S converter (8 parallel bits)
25-32	Bilevel	Power amplifier (8 parallel bits)
33-40	Bilevel	Preamplifiers (8 parallel bits)
41-56	Bilevel	Tracking receivers (8 parallel bits each)
57-72	Bilevel	Antenna controllers (8 parallel bits each)
73	Analog	S-K converter
74	Analog	K-S converter
75-77	Analog	Power amplifier
78-80	Analog	Preamplifier
81-83	Analog	Tracking receivers (3 each)
83-86	Analog	Antenna controllers (3 each)
72	Bilevel	Total
14	Analog	

2.3 Carrier Modem Group

The carrier modem group consists of linear phase modulators and demodulators, linear frequency modulators and demodulators, biphase modulators and demodulators, and quadriphase modulators. A set of these equipments is located in SM-1 and SM-4. A description of the functional characteristics of each equipment type follows.

2.3.1 Carrier Phase Modulators

Two linear phase modulators (one operational and one spare) are provided for use on the S band links to the ground. Up to three simultaneous subcarrier inputs are linearly summed prior to modulation. The gain of each summer input channel is set by control group command as required. The gains of unused input channels are set to zero. The modulator's carrier frequency is derived from a frequency reference on the reference frequency bus and can be varied by control group command.

Each phase modulator has provisions for continuously monitoring its modulation sensitivity. One or more low level pilot tones are inserted in the baseband by the summer and detected at the modulator output. These parameters are reported to the DPA via the control group and may be used internally by the modulator to automatically adjust the gains of the input channels as required.

2.3.2 Carrier Frequency Modulators

Two operational and one spare linear frequency modulators are provided for use on the K band and shuttle links. Up to three simultaneous inputs are linearly summed prior to modulation. The gain of each summer input channel is set by control group command as required. The gains of unused input channels are set to zero. The modulator's carrier frequency is derived from a frequency reference on the reference frequency bus and can be varied by control group command.

Each frequency modulator has provisions for continuously monitoring its modulation sensitivity. One or more low level pilot tones is inserted in the baseband by the summer and detected at the modulator output. These parameters are reported to the DPA via the control group and may be used internally by the modulator to automatically adjust the gains of the input channels as required.

2.3.3 Carrier Phase Demodulators

One operational and one spare phase demodulator are provided for use on the S band links to the ground. The input to each demodulator comes from its corresponding downconverter in the S band group. Each demodulator provides isolated outputs to subcarrier demodulators in the subcarrier modem group and the ranging receiver in the S band group. The demodulator's carrier search range and search rate are controlled by command from the control group. The demodulator's AGC voltage is provided as an output and a carrier acquisition signal is provided as a bilevel output for periodic sampling by the control group.

2.3.4 Carrier Frequency Demodulators

Two operational and one spare frequency demodulators are provided for use on the K band and shuttle links. The input to each demodulator comes from its corresponding downconverter in the S band group. Each demodulator provides isolated outputs to subcarrier demodulators in the subcarrier modem group. The demodulator's carrier search range and search rate are controlled by command from the control group. The demodulator's AGC voltage is provided as an analog output and a carrier acquisition signal is provided as a bilevel output for periodic sampling by the control group.

2.3.5 Carrier Quadriphase Modulators

One operational and one spare quadriphase modulator are provided for use when the ECA operates in the TDM-only mode. Each modulator's input is from a channel encoder in the TDM group and its output goes to its corresponding upconverter in the S band group. The modulator's carrier frequency is derived from a frequency reference on the reference frequency bus and can be varied by control group command.

2.3.6 Carrier Biphase Modulators

One operational and one spare carrier biphase modulator are provided for use on the S band, TDRS backup link. Each modulator's input is from its corresponding low data rate channel encoder in the TDM group and its output goes to its corresponding upconverter in the S band group. Each modulator operates at a fixed data rate of 140 kbps and its carrier frequency is derived from a frequency reference on the reference frequency bus and can be varied by control group command.

2.3.7 Carrier Biphase Demodulators

One operational and one spare carrier biphase demodulator are provided for use on the S band, TDRS backup link. Each demodulator's input is from its corresponding downconverter in the S band group and its output goes to its corresponding channel decoder in the TDM group. The demodulator's carrier search range and search rate are controlled by command from the control group. Each demodulator derives its carrier reference and bit timing from its data input and operates at a fixed data rate of 60 kbps.

The demodulator's AGC voltage and detected carrier reference phase jitter are provided as analog outputs for periodic sampling by the control group. Carrier and bit sync acquisition signals are also provided as bilevel outputs.

2.3.8 Control and Monitoring

The carrier modem group responds to the control group commands listed in Table V and provides the signal outputs listed in Table VI for periodic monitoring by the control group.

TABLE V. CARRIER MODEM GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1	Pulse	Phase modulator A - On
2	Pulse	Phase modulator A - Off
3-20	Pulse	Modulators - On and Off
21-34	Pulse	Demodulators - On and Off
35-39	Serial	Modulators' summer gains
40-48	Serial	Modulators' carrier frequency
49-57	Serial	Demodulators' search range and rate
34	Pulse	Total
23	Serial	

TABLE VI. CARRIER MODEM GROUP MONITORED PARAMETERS

Signal Number	Signal Type	Signal Monitored
1	Bilevel	Phase modulator A - On/Off
2-9	Bilevel	Modulators - On/Off
10-16	Bilevel	Demodulators - On/Off
17-70	Bilevel	Modulators' summer gains (4 per input)
71-79	Analog	Modulators' oscillator drive level
80-86	Analog	Demodulators' search range and rate
87-93	Analog	Demodulators' AGC voltage
94-100	Bilevel	Demodulators' squelch - On/Off
101-107	Bilevel	Demodulators' carrier acquisition

TABLE VI (continued)

Signal Number	Signal Type	Signal Monitored
108-109	Bilevel	Biphase demodulators' bit sync acquisition
110-111	Analog	Biphase demodulators' phase jitter
86	Bilevel	Total
25	Analog	

2.4 Subcarrier Modem Group

The subcarrier modem group consists of biphase, quadriphase and linear frequency modulators and biphase and linear frequency demodulators. A set of these equipments is located in SM-1 and SM-4. A description of the functional characteristics of each equipment type follows.

2.4.1 Subcarrier Biphase Modulators

Six subcarrier biphase modulators are provided for system data and multiplexed digital voice transmission. This number satisfies the maximum simultaneous demand with the K band, shuttle, and ground links all operating. Each modulator's subcarrier is derived from a frequency reference on the reference frequency bus and can be varied by control group command. A clock input, synchronized to the data input, is provided to the modulator.

2.4.2 Subcarrier Quadriphase Modulators

One operational and one spare subcarrier quadriphase modulator are provided for experiment data transmission. The modulator's fixed subcarrier frequency is derived from the reference frequency bus. A clock input, synchronized to the data input, is provided to the modulator.

2.4.3 Subcarrier Frequency Modulators

One operational and one spare subcarrier frequency modulator are provided for analog facsimile transmission. The modulator derives its fixed subcarrier frequency from the reference frequency bus. The modulation index can be varied by control group command.

2.4.4 Subcarrier Biphase Demodulators

Six subcarrier biphase demodulators are provided for control and computer data, text and graphics, and multiplexed digital voice and music entertainment data reception. This number satisfies the maximum

simultaneous demands with the K band, shuttle, and ground links all operating. Each demodulator derives its subcarrier reference and bit timing from its data input. The subcarrier frequency and bit rate for each demodulator are selectable by command from the control group.

The phase jitter in the demodulator's subcarrier reference is detected and provided as an analog output for periodic sampling by the control group. Subcarrier and bit sync acquisition signals are also provided as bilevel outputs for periodic sampling by the control group.

2.4.5 Subcarrier Frequency Demodulators

One operational and one spare subcarrier frequency demodulator are provided for facsimile reception. If required, a subcarrier reference is derived from the input signal. The phase jitter in this subcarrier reference is detected and provided as an analog output for periodic sampling by the control group. A subcarrier acquisition signal is also provided as a bilevel output for periodic sampling by the control group.

2.4.6 Control and Monitoring

The subcarrier modem group responds to the control group commands listed in Table VII and provides the signal outputs listed in Table VIII for periodic monitoring by the control group.

TABLE VII. SUBCARRIER MODEM GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1	Pulse	Biphase modulator A - On
2	Pulse	Biphase modulator A - Off
3-20	Pulse	Modulators - On and Off
21-28	Pulse	Demodulators - On and Off
29-34	Serial	Modulators' frequency
35-36	Serial	Modulation index
37-42	Serial	Biphase demodulator bit rate
43-48	Serial	Biphase demodulator frequency
28	Pulse	Total
20	Serial	

TABLE VIII. SUBCARRIER MODEM GROUP MONITORED PARAMETERS

Signal Number	Signal Type	Signal Monitored
1	Bilevel	Biphase modulator A - On/Off
2-10	Bilevel	Modulators - On/Off
11-18	Bilevel	Demodulators - On/Off
19-28	Analog	Modulators' oscillator drive level
29-34	Bilevel	Demodulators' bit rate range
35-42	Analog	Demodulators' reference jitter
43-50	Bilevel	Demodulators' subcarrier acquisition
51-56	Bilevel	Demodulators' bit sync acquisition
38	Bilevel	Total
18	Analog	

2.5 TDM Group

The TDM group consists of low rate and high rate digital multiplexers, digital demultiplexers, and channel encoders and decoders. A set of these equipments is located in SM-1 and SM-4. A description of the functional characteristics of each equipment type follows.

2.5.1 Low Rate Digital Multiplexers

Six low rate digital multiplexers are provided for multiplexed digital voice and system data transmission. One operational and one spare multiplexer are assigned to the backup S band TDRS link, and three operational and one spare multiplexer are assigned to the K band, shuttle and ground links. The multiplexer accepts either three 19.2 kbps inputs and interleaves these on a bit-by-bit basis with periodic sync words to form a 60 kbps output or it multiplexes a single 19.2 kbps and a 50 kbps with sync words to form a 70 kbps output.

The multiplexers are configured for either mode by command from the control group. The control group also provides timing.

2.5.2 High Rate Digital Multiplexer

One operational and one spare high rate digital multiplexer are used in the TDM-only mode. The multiplexer format is to be determined. Timing for the multiplexers is provided by the control group.

2.5.3 Digital Demultiplexers

Six digital demultiplexers are provided for 1) multiplexed digital voice, 2) digital voice and entertainment, and 3) digital voice and system data reception. The corresponding multiplexer input rates are 60, 200, and 70 kbps. The parallel outputs are: 1) three 19.2 kbps digital voice, 2) three 19.2 kbps digital voice and one 140 kbps PCM entertainment channel, and 3) one 19.2 kbps digital voice and 50 kbps data. One operational and one spare demultiplexer are assigned to the backup S band TDRS link and three operational and one spare multiplexer are assigned to the K band, shuttle, and ground links.

The demultiplexers are configured for either of the three configurations by commands from the control group. Timing for each demultiplexer is provided by its corresponding subcarrier biphase demodulator or channel decoder.

2.5.4 Low Rate Channel Encoder

One operational and one spare low rate channel encoder are provided for encoding the digital stream on S band, TDRS backup link. The encoder accepts a 70 kbps serial input and convolutionally encodes this at rate 1/2, constraint length 7. Timing for each encoder is provided by the control group.

2.5.5 High Rate Channel Encoder

One operational and one spare high rate channel encoder are provided for encoding the TDM-only mode transmission. The encoder accepts the output of the high rate multiplexer and encodes this before passing it to the quadriphase carrier modulator. The code constraint length is to be determined. Timing is provided by the control group.

2.5.6 Low Rate Channel Decoder

One operational and one spare low rate decoder are provided for reception of the S band, TDRS backup link. These are maximum likelihood, convolutional decoders. The code parameters are rate 1/2, constraint length 7. The input bit rate from the carrier demodulator is 60 kbps and a 30 kbps decoded output is provided to the digital demultiplexers. Timing for each decoder is provided by its corresponding carrier demodulator.

2.5.7 Control and Monitoring

The TDM group responds to the control group commands listed in Table IX and provides the signal outputs listed in Table X for periodic monitoring by the control group.

TABLE IX. TDM GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1-12	Pulse	Low rate multiplexers - On and Off
13-16	Pulse	High rate multiplexers - On and Off
17-28	Pulse	Digital demultiplexers - On and Off
29-32	Pulse	Low rate channel encoders - On and Off
33-36	Pulse	High rate channel encoders - On and Off
37-40	Pulse	Low rate channel decoders - On and Off
41-42	Serial	Low rate multiplexer rate and inputs
43-44	Serial	Digital demultiplexer rate and inputs
40	Pulse	Total
4	Serial	

TABLE X. TDM GROUP MONITORED PARAMETERS

Signal Number	Signal Type	Signal Monitored
1-6	Bilevel	Low rate multiplexers - On/Off
7-8	Bilevel	High rate multiplexers - On/Off
9-14	Bilevel	Digital demultiplexers - On/Off
15-16	Bilevel	Low rate channel encoders - On/Off
17-18	Bilevel	High rate channel encoders - On/Off

TABLE X (continued)

Signal Number	Signal Type	Signal Monitored
19-20	Bilevel	Low rate channel decoders - On/Off
21-38	Bilevel	Low rate multiplexer rate and inputs
39-56	Bilevel	Digital demultiplexer rate and inputs
56	Bilevel	Total
0	Analog	

2.6 Delta Modem Group

The delta modem group consists of delta modulators, delta demodulators, and digital/analog converters. A set of these equipments is located in SM-1 and SM-4. A description of the functional characteristics of the equipment types follows.

2.6.1 Delta Modulators

Five delta modulators are provided to encode analog voice waveforms into a 19.2 kbps serial data. The encoding technique must be compatible with the encoding of inband supervisory signals associated with establishing the circuit through ground switchboards. Timing is provided by the control group.

2.6.2 Delta Demodulators

Five delta demodulators are provided to recover a voice waveform from a 19.2 kbps serial data. The encoding technique must be compatible with the decoding of inband supervisory signals used with the telephone switchboard of the ICA. Timing is provided by the associated digital demultiplexers.

2.6.3 Digital/Analog Converters

Each digital/analog converter converts a 140 kbps serial data to a 10 kHz music/entertainment analog signal. The input data format is 7 bit PCM. Timing is provided by the converter's associated digital demultiplexers.

2.6.4 Control and Monitoring

The delta modem group responds to the control group commands listed in Table XI and provides the signal outputs listed in Table XII for periodic monitoring by the control group.

TABLE XI. DELTA MODEM GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1	Pulse	Delta modulator A - On
2	Pulse	Delta modulator A - Off
3-10	Pulse	Delta modulators - On and Off
11-20	Pulse	Delta demodulators - On and Off
21-24	Pulse	Digital/analog converters - On and Off
24	Pulse	Total
0	Serial	

TABLE XII. DELTA MODEM GROUP MONITORED PARAMETERS

Signal Number	Signal Type	Signal Monitored
1	Bilevel	Delta modulator A - On/Off
2-5	Bilevel	Delta modulators - On/Off
6-10	Bilevel	Delta demodulators - On/Off
11-12	Bilevel	Digital/analog converters - On/Off
12	Bilevel	Total
0	Analog	

2.7 Baseband Switching Group

The baseband switching group consists of all the switches, and their associated control circuits, which connect the inputs and outputs of the baseband communication equipment to provide the commanded baseband equipment configuration. A set of these equipments is located in SM-1 and SM-4. A description of the functional characteristics of the equipment follows.

2.7.1 Baseband Switches

The baseband switches consist of matrices of switch elements, each element having one input and several outputs. At any one time, the input is connected via the switch element to, at most, one output and isolated from all other outputs.

Baseband switch A connects analog voice inputs from the audio-video unit to the delta modem group and analog facsimile inputs to the carrier modem group. Baseband switch B connects the digitized voice outputs from the delta modem group to the TDM group and digital systems and experiments data inputs to the TDM group and the subcarrier modem group. Baseband switch C connects analog subcarriers from the subcarrier modem group and ranging group to the carrier modem group.

Baseband switch D connects the analog subcarrier outputs of the carrier modem group to the subcarrier modem group and ranging group. Baseband switch E connects the digitized voice outputs of the TDM group to the delta modem group and the digital outputs from the subcarrier modem group to the telemetry bus. Baseband switch F connects the analog outputs of the delta modem group to the audio-video unit and the facsimile output of the subcarrier modem group to the facsimile output line.

Baseband switches A, B, and C provide outputs to test translators in the control group which connect these signals to baseband switches D, E, and F for purposes of loop testing.

Each switch matrix includes associated switch junction logic and driver circuitry to decode input/output configuration commands from the control group. Configuration changes causing the addition or deletion of selected connectors shall be possible without disrupting the other connections in the field. Table XIII lists the minimum number of input and output junctions provided by each switch.

TABLE XIII. BASEBAND SWITCH CAPACITIES

Switch	Minimum Number of Inputs	Minimum Number of Outputs
A	5	9
B	9	30
C	16	21
D	18	10
E	23	11
F	11	7

2.7.2 Control and Monitoring

The baseband switching group responds to the control group commands listed in Table XIV. The status of the switch junctions listed in Table XV is provided as outputs for periodic monitoring by the control group.

TABLE XIV. BASEBAND SWITCHING GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1	Pulse	Baseband switches power - On
2	Pulse	Baseband switches power - Off
3	Serial	Switch A configuration
4	Serial	Switch B configuration
5	Serial	Switch C configuration
6	Serial	Switch D configuration
7	Serial	Switch E configuration
8	Serial	Switch F configuration
2	Pulse	Total
6	Serial	

TABLE XV. BASEBAND SWITCHING GROUP MONITORED PARAMETERS

Signal Number	Signal Type	Signal Monitored
1	Bilevel	Baseband switches power - On/Off
2-19	Bilevel	Switch A configuration
20-50	Bilevel	Switch B configuration
51-110	Bilevel	Switch C configuration
111-170	Bilevel	Switch D configuration

TABLE XV (continued)

Signal Number	Signal Type	Signal Monitored
171-200	Bilevel	Switch E configuration
201-235	Bilevel	Switch F configuration
235	Bilevel	Total
0	Analog	

2.8 Control Group

The control group of the ECA is composed of a central unit, a multiplex data link, and up to 16 remote multiplexer/demultiplexer units (Figure 3). The redundant frequency synthesizers and test translators are also included in this group. A set of these equipments is located in SM-1 and SM-4. The remote multiplexer-demultiplexer units interface with the communication equipment of the ECA, providing interfaces in the quantity and types specified in Tables XVI and XVII. The remote multiplexer units transmit commands, parameter values, and test signals from the central unit, and sample analog and bilevel discrete data and transmit these data to the central unit.

TABLE XVI. SUMMARY OF ECA CONTROL COMMANDS

Number of Commands	Command Type	ECA Group
52 20	Pulse Serial	S band
15 4	Pulse Serial	K band
34 23	Pulse Serial	Carried modem
28 20	Pulse Serial	Subcarrier modem
40 4	Pulse Serial	TDM

TABLE XVI (continued)

Number of Commands	Command Type	ECA Group
24 0	Pulse Serial	Delta modem
2 6	Pulse Serial	Baseband switching
44 12	Pulse Serial	Control
239 89	Pulse Serial	Total

TABLE XVII. SUMMARY OF ECA MONITORED PARAMETERS

Number of Signals	Type of Signals	ECA Group
202 88	Bilevel Analog	S band
72 14	Bilevel Analog	K band
86 25	Bilevel Analog	Carrier modem
38 18	Bilevel Analog	Subcarrier modem
56 0	Bilevel Analog	TDM
12 0	Bilevel Analog	Delta modem
235 0	Bilevel Analog	Baseband switching
36 40	Bilevel Analog	Control
737 185	Bilevel Analog	Total

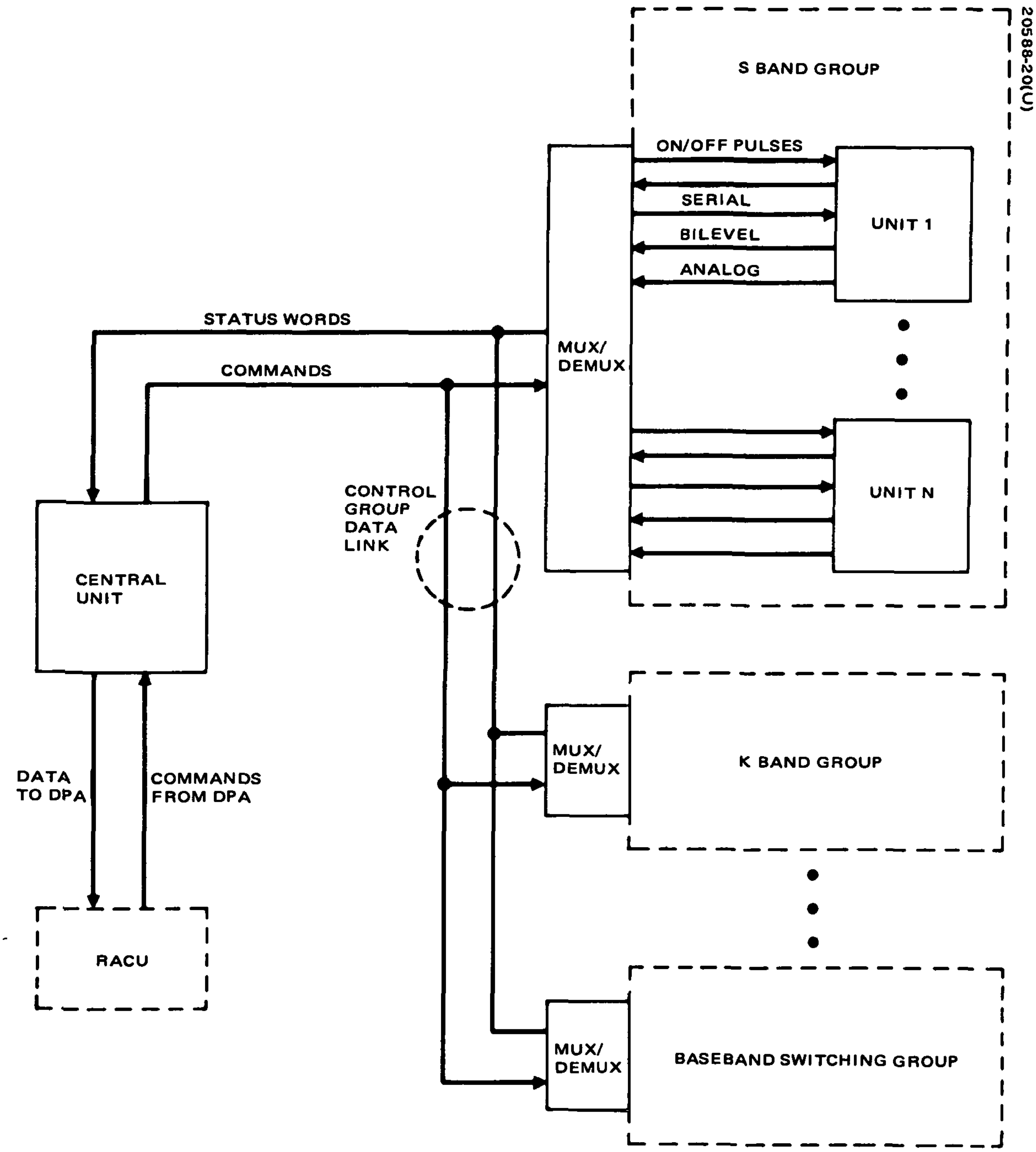

Figure 3. ECA Control and Monitoring Circuits

2.8.1 Central Unit

The control group central unit is a programmable command processor. It receives commands from and transmits data to the data processing assembly (DPA) through a remote acquisition and control unit (RACU). It processes the commands received and retransmits them to the remote multiplexer/demultiplexers. The functions of the central unit are described below.

2.8.1.1 Equipment Selection

The central unit memory stores the status of each unit of communication equipment in the ECA. For each unit in use in a communication link, a tag identifying the communication link is stored. If a unit is not in use, the memory contains bits indicating whether the unit is available for use or is defective. Then the DPA wishes to use equipment in a communication link, it first transmits a 6 bit tag to identify the communication link, and then serially identifies the required equipment types to the central unit. The central unit searches its memory until it finds a unit of this type which is available for use, whereupon it assigns it to the communication link, and stores in memory the fact that the item of equipment is in use in that link. When a link is to be dismantled, the DPA identifies each type of equipment to be turned off in turn, and the central unit searches memory until it locates the unit of that type which is associated with the link being dismantled. Malfunctioning equipment is never assigned to a communication link unless specifically requested by the DPA.

2.8.1.2 Command Generation

Since the central unit determines which individual item of equipment shall be used for each application, it must itself generate the command outputs to turn the equipment on and off. In addition, the central unit stores the switch control bits necessary to access the input and output of each piece of equipment, and from these formulates commands to open and close the switch junctions that connect the chosen units of communication equipment into a communication link.

2.8.1.3 Data Interface With DPA

The central unit interfaces with the RACU to provide for the two-way transfer of data between the ECA and the DPA.

2.8.2 Central Unit/DPA Interface

The control group central unit receives commands from and transmits data to the DPA under the DPA's control. Commands and data are transferred in the form of 8 bit serial NRZ data with clock for both the receive and transmit functions provided by the RACU. Data are transferred on the falling edge of the data clock waveforms.

2.8.2.1 DPA to Control Group Central Unit

The data format employed by the DPA to send commands and data to the control group is shown in Table XVIII. Each transmission consists of

TABLE XVIII. DPA COMMAND STRUCTURE

1	2	3	4	5	6	7	8

Bit 1 = command identification

Logic 1 = primary word of a command

Logic 0 = supplementary command word

For Bit 1 = 1:

Bits 2 - 5 = command type

Type No.	2	3	4	5	
0	0	0	0	0	= establish mode
1	0	0	0	1	= discontinue mode
2	0	0	1	0	= turn on unit
3	0	0	1	1	= turn off unit
4	0	1	0	0	= unit defective
5	0	1	0	1	= unit no longer defective
6	0	1	1	0	= parameter value follows
7	0	1	1	1	= report data word
8	1	0	0	0	= finish establishing mode
9	1	0	0	1	= finish disconnecting mode
10	1	0	1	0	= re-tag unit
11	1	0	1	1	= identify unit
12	1	1	0	0	= spare
13	1	1	0	1	= spare
14	1	1	1	0	= spare
15	1	1	1	1	= spare

Bits 6, 7 = as required

Bit 8 = parity

two or more 8 bit words. The first or primary word (which is identified by the presence of a logic "1" in the first bit position) defines the type of command, and thus the action which the central unit takes to execute the command. The following supplementary word or words provide the additional information necessary for execution of the command. If a parameter value is to be sent to a unit, this fact is identified by the primary command word, and the parameter is identified and its value given in supplementary words.

2.8.2.2 DPA Command Structure

The structure of the commands from the DPA to the control group is as follows:

Command Types 0, 1 (Table XIX). These commands are sent to the control group to indicate that a command link will be assembled or disassembled by the following series of commands. They provide a 6 bit tag that the control group uses to identify the communication link (link tag, bits 2-7 of second supplementary word), and identify the source of the information to be transferred. (The format allows 16 input types to be handled, and one of 16 inputs of each type to be selected).

TABLE XIX. COMMAND TYPES 0, 1

Bits 6-7 of primary word plus bits 2-4 of first supplementary word	=	input type (switch number)
Bits 5-8 of first supplementary word	=	input number (switch input)
Bit 8 of second supplementary word	=	parity of entire command

Command Types 2, 3 (Table XX). After the DPA has transmitted commands of types 1 or 2, indicating that a communication link is to be assembled or dismantled, a series of commands of type 2 or 3 is sent to command the control group to turn on or off communication equipment units of the ECA as necessary. Each command of type 2 or 3 consists of a primary word followed by two supplementary words, and identifies the generic type of equipment to be turned on or off (unit type, bits 6-8 of the first supplementary data word). The choice of an actual unit of equipment to turn on or off is usually made by the control group central unit. However, the data processing assembly has the capability of commanding any particular unit on or off for test or failure correction purposes. If it wishes to define the particular unit, bit 6 of the primary command word is set to logic "1" and the unit is identified by bits 2-7 of the second supplementary word. When the choice is to be made by the control group central unit, these bits are set to the zero state.

TABLE XX. COMMAND TYPES 2 AND 3

Word	Bits	Function
S1	2-5	Multiplexer/demultiplexer address
S1	6-8	Unit type

TABLE XX (continued)

Word	Bits	Function
P	6	If 0, select available unit or unit identified with current tag → No further secondary words will be transmitted. If 1, operate on unit number define by second supplementary word
S2	2-7	Number of unit
S2	8	Parity

Command Types 4, 5, 10 (Table XXI). These commands are transmitted by the DPA when it wishes to alter the status record of a particular unit stored in the control group central unit memory. The generic type of unit and the specific unit are identified by the unit type and unit number bits in the supplementary command words. Command type 4 is sent if test data have indicated that a unit is not functioning as specified and should not be used in communication links. This command causes the central unit to identify the unit as defective. Command type 5 is used to remove the defective notation when the unit has been replaced or other action has been taken so that it should once again be considered operative. Command type 10 causes the central unit to store the tag of the data link being assembled or disassembled at the moment in the memory slot corresponding to some particular unit without transmitting commands to the unit. This command is used to transfer segments of an existing communication link into a new link, without the necessity of first turning them off and then assigning them to the new link.

TABLE XXI. COMMAND TYPES 4, 5, AND 10

Word	Bits	Function
S1	2-5	Multiplexer/demultiplexer address
S1	6-8	Unit type
S2	2-7	Unit number
S2	8	Parity on all supplementary data words

Command Type 6 (Table XXII). This command type causes the control group to output serial digital data from the DPA without alteration in one of its serial, binary outputs. The multiplexer/demultiplexer and input are addressed. No parity is included in the words that contain only transferred data since some units may not require parity. If parity is needed, it is inserted into the data by the DPA and checked only by the receiving ECA unit.

TABLE XXII. COMMAND TYPE 6

Word	Bits	Function
S1	2-5	Multiplexer/demultiplexer address
S1	6-8	Output number
S2	2-4	Output number
S2	5	Parity on word S1 and S2 bits 2-4
S2	6-8	Data
S3	2-8	Data
.	.	.
.	.	.
.	.	.

Command Type 7 (Table XXIII). A command of this type is sent to cause the control group to sample one of its inputs and transmit the information to the DPA. The multiplexer/demultiplexer and input are identified, and a 2 bit request tag is also included. This tag is returned to the DPA along with the requested data as an identifier. It enables up to four data requests to be made by the DPA before the data have been returned by the control group, yet eliminates the necessity of transmitting the entire input identifier along with the data.

TABLE XXIII. COMMAND TYPE 7

Word	Bits	Function
Primary	6-7	Data request tag
S1	2-5	Multiplexer/demultiplexer address
S1	6-8	Input number
S2	2-4	Input number
S2	8	Parity on supplementary words

Command Types 8, 9 (Table XXIV). These commands are analogous to command types 1 and 2, except that they are sent to complete the assembly or disassembly of a communication link. The commands are necessary to define the final output of the communication link. The switch control bits necessary to identify the output are transmitted in bit positions 5-8 of the first supplementary data word. The 6 bit communication path tag is repeated.

TABLE XXIV. COMMAND TYPES 8 AND 9

Bits 6-7 of primary word, 2-4 of first supplementary word	=	0
Bits 5-8 of first supplementary word	=	output number
Bits 2-7 of second supplementary word	=	mode tag
Bit 8 of second supplementary word	=	parity on entire command

Command Type 11 (Table XXV). This command type is used when the DPA wishes to know which unit of a particular type is performing in a particular communication link. It transmits the equipment type and the link tag to the central unit, which searches its memory to find the unit of that type with that tag, and returns a data word to the DPA containing the unit number bits. This command type is used primarily for fault isolation and performance monitoring.

TABLE XXV. COMMAND TYPE 11

Word	Bits	Function
S1	2-5	Multiplexer/demultiplexer address
S1	6-8	Unit type
S2	2-7	Unit tag

2.8.2.3 Control Group Central Unit to DPA Data Structure

The control group central unit verifies execution of commands and transmits multiplexed data to the DPA in the format shown in Table XXVI. The first bit of each word identifies whether the word is the initial word in a message or a later word. If the message is to verify execution of a command, only one word is used. If data are to be transmitted, the data are identified by the first word and the data are contained in the following word or words. If a command is received from the DPA which fails parity or any other validity check performed by the central unit, the command is not executed by the control group, and instead, the central unit transmits a "previous command invalid" word to the DPA.

TABLE XXVI. CONTROL GROUP TO DPA DATA FORMAT

8 bit NRZ words to DPA; clock provided by DPA

Bit 1 = identification

Logic 1 = first word of message

Logic 0 = other words

Bits 2-5 = data message type (command type to which data are a response)

Type No.	2	3	4	5		
0	0	0	0	0	=	establish mode
1	0	0	0	1	=	discontinue mode
2	0	0	1	0	=	turn on unit
3	0	0	1	1	=	turn off unit
4	0	1	0	0	=	unit defective
5	0	1	0	1	=	unit no longer defective
6	0	1	1	0	=	parameter received
7	0	1	1	1	=	data words follow
8	1	0	0	0	=	finish establishing mode
9	1	0	0	1	=	finish disbanding mode
10	1	0	1	0	=	re-tag unit
11	1	0	1	1	=	identify unit
12	1	1	0	0	=	previous command invalid
13	1	1	0	1	=	spare
14	1	1	1	0	=	spare
15	1	1	1	1	=	spare

Bits 6-7 = as required, bit 8 = parity

Message types 0-6, 8-10 are sent as programmed to verify execution of commands

TABLE XXVI (continued)

Message Types 7, 11

Word	Bits	Function
P	6-7	Repeats request tag
S_N	2-7	Requested data

When the central unit wishes to send data to the DPA, it provides a logic signal to the RACU indicating that it requires access to the bus. It then waits for a signal from the RACU indicating that data may be sent. When this signal is received, the central unit provides its data synchronous with the clock provided by the RACU.

2.8.3 Control Group/ECA Equipment Interfaces

The control group control and monitoring interfaces with the other equipment of the ECA are through the remote multiplexer/demultiplexers. These remote multiplexer/demultiplexers provide command and data outputs to the equipment, and sample bilevel discrete data and analog data provided by the equipment. All actions of the remote multiplexer/demultiplexer take place in response to commands from the control group central unit. The outputs of the remote multiplexer/demultiplexer include pulse command outputs and serial digital outputs, and the inputs to the remote multiplexer include analog inputs and bilevel discrete inputs.

2.8.3.1 Pulse Command Outputs

The remote multiplexer/demultiplexer utilizes pulse command outputs to cause binary changes of state in the ECA equipment. Each remote multiplexer/demultiplexer provides up to 32 pulse command outputs. The electrical interface of the pulse command outputs corresponds to the binary driver specified in Section 3.7.2. The pulse command outputs normally remain in the logic "0" state. When a pulse command is to be sent, the appropriate pulse command output goes to logic "1" state and then returns to the zero state.

2.8.3.2 Serial Digital Outputs

Each multiplexer/demultiplexer provides up to 32 serial digital outputs by which parameter values and other information are sent to the ECA units. The multiplexer/demultiplexer provides data present, data clock, and NRZ data signals with the electrical characteristics of the binary driver defined in

Section 3.7.2. When a word of serial digital data is to be outputted, first the data-present line goes to the logic "1" state. Then, after a delay period, the first of a series of eight negative clock transitions occurs on the clock line. The state of each bit of data is present on the data line at the negative transitions of the clock line, and the next bit of NRZ data appears on the data line after the negative transition has been completed. The format and content of the 8 bits of data contained in the serial digital output word are as required for the operation of the ECA item of equipment receiving the data.

2.8.3.3 Bilevel Discrete Inputs

The remote multiplexer/demultiplexers accept bilevel discrete data inputs which it samples, multiplexes, and transmits to the DPA upon command. Binary data levels should be present at all times on these inputs, or no signal is sent to the ECA equipment when the bilevel discrete inputs are sampled by the remote multiplexer/demultiplexer. The electrical characteristics of the remote multiplexer/demultiplexer bilevel discrete inputs correspond to the binary receiver specified in Section 3.7.2. Each multiplexer/demultiplexer accepts up to 256 bilevel discrete inputs.

2.8.3.4 Analog Inputs

Each remote multiplexer accepts up to 32 analog data inputs from the ECA units. The analog data must be present continuously at the remote multiplexer/demultiplexer inputs, or no signal is transmitted to the ECA equipment when the analog inputs are sampled. The electrical characteristics of the remote multiplexer/demultiplexer analog inputs are as specified in Section 3.7.2.

2.8.4 Reference Frequency Synthesizer

The reference frequency synthesizer generates redundant reference carriers for the reference frequency bus. The frequencies on this bus provide the references on which the ECA's subcarrier and carrier frequencies are based. The reference frequency synthesizer uses the 10 MHz RACU clock to derive the reference carriers.

2.8.5 Test Translators

Test translators are provided for loop test purposes. Baseband and S band signals are buffered, frequency-translated, and level-adjusted by the test translators to facilitiate the testing of cascaded equipment for fault isolation.

Test translator AF connects baseband voice facsimile signals from baseband switch A to baseband switch F. This enables the audio-video unit voice outputs and the facsimile outputs to be fed directly back into the audio-video unit voice inputs and the facsimile inputs, respectively.

Test translator BE connects baseband delta modulated voice from baseband switch B to baseband switch E. This enables the delta modulator outputs to be fed directly into the delta demodulator inputs.

Test translator CD frequency-translates the various frequency and biphase-modulated subcarriers from baseband switch C to baseband switch D. This enables the facsimile subcarrier modulator output to be fed directly into the facsimile subcarrier demodulator input, the TDM voice subcarrier modulator output to be fed directly into the TDM voice subcarrier demodulator, and the system's data subcarrier modulator output to be fed directly into the control and computer data subcarrier demodulator (the data rate of the system's data is modified for compatibility).

Test translator RF frequency translates the various S band carriers from RF switch A to RF switch B. This enables the S band outputs of the upconverters to be fed directly into the inputs of the appropriate downconverters.

2.8.6 Control and Monitoring

The control group central unit is directly commanded and functionally evaluated by the DPA. The multiplexer/demultiplexers, test translators, reference frequency synthesizers, and special test signal generators organic to the communication equipment group are directly commanded and monitored by the control group for periodic testing. Estimates of these commands and monitored parameters are given in Tables XXVII and XXVIII, respectively.

TABLE XXVII. CONTROL GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1	Pulse	Test translator AF - On
2	Pulse	Test translator AF - Off
3 - 8	Pulse	Test translator - On/Off
9 - 12	Pulse	Test translator CD conversion frequency
13 - 16	Pulse	Test translator RF conversion frequency
17 - 40	Pulse	Test signal generators - On/Off
41 - 52	Serial	Test signal generators parameter set
53 - 56	Pulse	Reference frequency synthesizers On/Off
44	Pulse	Total
12	Serial	

TABLE XXVIII. CONTROL GROUP MONITORED PARAMETERS

Signal Number	Signal Type	Signal Monitored
1 - 4	Bilevel	Test translators - On/Off
5	Analog	Test translator CD local oscillator drive
6	Analog	Test translator RF local oscillator drive
7 - 18	Bilevel	Test signal generators - On/Off
19 - 54	Analog	Analog test signal parameter measurements
55 - 72	Bilevel	Digital test signal parameter measurements
73 - 74	Bilevel	Reference frequency synthesizer On/Off
75 - 76	Analog	Reference frequency synthesizer output
36	Bilevel	Total
40	Analog	

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3.0 EXTERNAL COMMUNICATION ASSEMBLY ELECTRICAL INTERFACE CHARACTERISTICS

3.1 K Band and S Band Groups

3.1.1 General Interface Characteristics

These interfaces shall be compatible with the RF equipment design as described in the NAR/ITT documentation listed in Section 1.2.

3.1.2 IF Interfaces

The IF input impedance and output impedance shall be 75 ohms with a return loss greater than 26 dB. Two input frequencies shall be provided 70 and 250 MHz; the passbands shall be ±15 and ±45 MHz, ±1 dB, respectively. The IF output frequency to the demodulators shall be 70 MHz with a passband of ±15 MHz ±1 dB. The input and output reference levels shall be -15 dBm. The output reference level stability shall be ±0.1 dB over 24 hours.

3.1.3 RF Interfaces

Two S band, semidirectional (0 dB) antennas shall be provided on each station module (SM-1 and SM-4). Each shall be driven by a 30 watt RF amplifier providing 14.8 dBw, EIRP. The S band receive system noise temperature with these same antennas shall be nominally 500°K. The S band RF bandwidth shall be 34 MHz.

A directional, K band antenna shall be provided on each station module which provides 44.5 dB gain. The antenna shall be driven by parallel 15 watt TWT amplifiers that provide 14 dBw RF power at the antenna terminals with both operating and 7.9 dBw with one operating. The transmit channel shall provide 100 MHz bandwidth within the band from 14.4 to 15.39 GHz.

The K band receiver operates over the band from 13.5 to 13.7 GHz and has 100 MHz bandwidth. The system noise temperature shall be nominally 1200°K.

3.1.4 Control and Monitoring

Control and monitoring interfaces shall be compatible with the control group interfaces as described in Section 3.7.

3.2 Carrier Modem Group

3.2.1 General Interface Characteristics

The input impedance and output impedance of all units in this group shall be 75 ohms with a return loss greater than 26 dB. The reference level output for all analog circuits shall be -15 dBm with a stability of ±0.1 dB

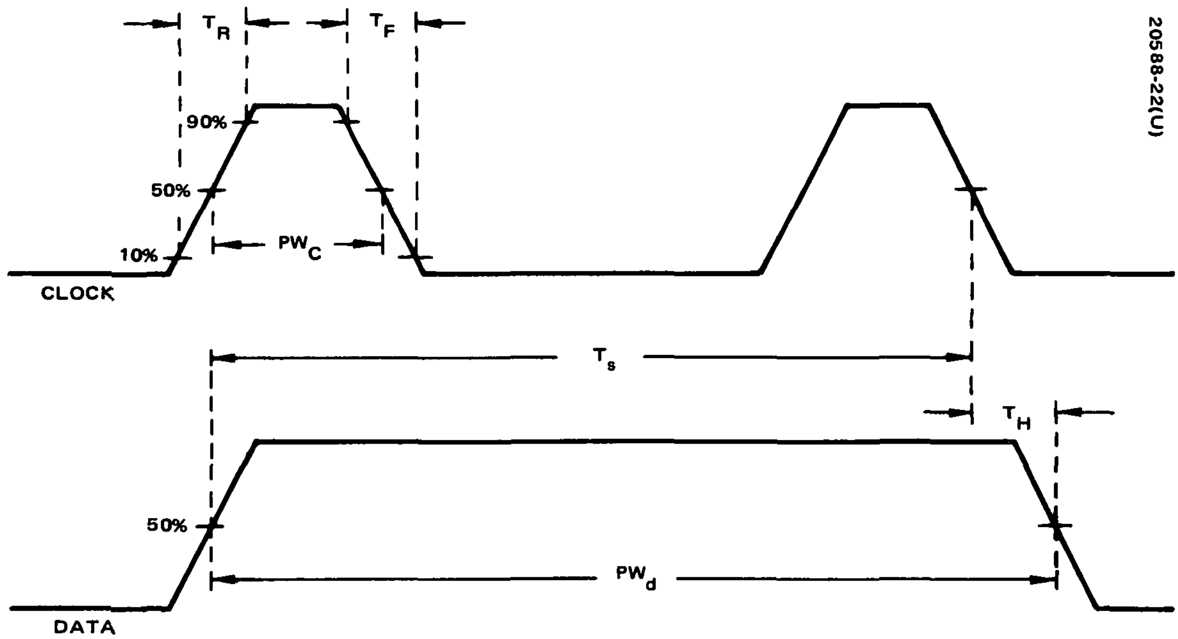

Figure 4. Serial Digital Timing

over 24 hours. The frequency stability of the modulator output IF carriers shall be 2 parts in 10^8 over 24 hours.

All digital interfaces shall conform to the levels specified in Tables XXIX (inputs) and XXX (outputs). The general timing diagram for all digital circuits is shown in Figure 4.

3.2.2 Quadriphase Carrier Modulator

The input shall accept a data pulse width of 83 nanoseconds (minimum) and a clock frequency of 12 MHz (maximum).

The output carrier frequency shall be 70 MHz. The modulation format shall be the four dibits (11, 10, 00, 01) cause the carrier reference phase to be changed 1, 3, 5, or 7 times $\pi/4$ ±1 percent radians.

All spurious and distortion products shall be less than -95 dBm in any 10 kHz from 65 to 75 MHz.

3.2.3 Biphase Carrier Modulator

The input shall accept a data pulse width of 7.1 microsecond (minimum) and a clock frequency of 140 kHz (maximum).

The output carrier frequency shall be 70 MHz. The modulation format shall be $\pm\pi/2$ ±1 percent radians change from carrier reference phase for logical "1" and logical "0"; the modulation sense shall be reversible by command.

All spurious and distortion products shall be less than -95 dBm in any 10 kHz from 68.9 to 71.1 MHz.

3.2.4 Linear FM Carrier Modulator

Three input channels shall be provided. The reference level for each input shall be -15 dBm. The channel gain shall be controlled by command +6 dB, -54 dB in 1 dB steps, an off-position shall also be provided for each channel with 60 dB attenuation. The frequency response of all channels shall be within ±0.5 dB from 30 Hz to 9.09 MHz.

The output carrier frequency shall be 70 or 250 MHz selectable by command. The maximum carrier deviation at 250 MHz with 1 percent linearity shall be ±50 MHz. The reference level deviation shall be ±40 MHz.

All spurious and distortion products shall be less than -95 dBm in any 10 kHz from 200 to 300 MHz for 250 MHz IF output and from 68.2 to 71.8 MHz for the 70 MHz IF output.

TABLE XXIX. BINARY RECEIVER CHARACTERISTICS

Characteristic	Test Conditions	Value
V_{in} 1 Minimum input voltage for logic "1" response		2.0 volts
V_{in} 0 maximum input voltage for logic "0" response		0.8 volt
I_{in} 1 logic "1" level input current (maximum)	$V_{in} = 2.4$ volts $V_{in} = 5.5$ volts	50 microamperes 1 milliampere
I_{in} 0 maximum logic "0" level input current	$V_{in} = 0.4$ volt	-2 milliamperes

TABLE XXX. BINARY DRIVER CHARACTERISTICS

Characteristic	Test Conditions	Value
V_{out} 1 minimum logical "1" output voltage	$I_{load} = -500$ microamperes	2.4 volts
V_{out} 0 maximum logical "0" output voltage	$I_{sink} = 16$ milliamperes	0.4 volt

3.2.5 Linear PM Carrier Modulator

Three input channels shall be provided. The reference level for each input shall be -15 dBm. The channel gain shall be controlled by command +6 dB, -30 dB in 1 dB steps. An off-position shall be provided for each channel with 60 dB attenuation. The frequency response of all channels shall be within ±0.5 dB from 30 Hz to 2.727 MHz.

The output carrier frequency shall be 70 MHz. The maximum carrier deviation (1 percent linearity) for a 2.727 MHz input carrier shall be ±2.9 MHz. The reference level deviation at 2.0 MHz shall be ±65 kHz.

All spurious and distortion products shall be less than -95 dBm in any 10 kHz from 67.9 to 72.9 MHz.

3.2.6 Biphase Carrier Demodulator

The IF input shall be 70 ±0.5 MHz. The reference input level corresponding to a 9.2 dB carrier-to-noise power ratio shall be -30 dBm and it shall accept up to 20 dB overdrive without degradation. The input signal format shall be $\pm\pi/2$ radians change from carrier reference phase for logical "1" and logical "0"; the modulation sense shall be reversible by command.

The minimum output pulse width shall be 16.6 microseconds and the maximum output clock frequency shall be 60 kHz. The output pulse shape and level shall be met when terminated in 75 ohms shunted by 100 picofarads.

The bit error rate for the reference input shall be equal to or less than 1 in 10^5. Initial bit synchronization, including assisted carrier acquisition, shall be achieved in 2 seconds at input signal levels corresponding to a BER of 1 in 10^3. Resynchronization shall be accomplished within 1000 bit periods and shall be maintained for at least 500 bit periods after loss of signal.

3.2.7 Linear FM Carrier Demodulator

The IF input shall be 70 ±0.5 MHz. The reference input level (threshold) shall be -30 dBm at an IF carrier to noise power ratio of 6.0 dB and a deviation of ±2.6 MHz. The demodulator shall accept up to 20 dB overdrive without degradation.

Three output channels shall be provided with 50 dB isolation between worst case pairs. The output frequency response of each channel shall be ±0.5 dB from 30 Hz to 1.6 MHz with 1 percent maximum distortion. The output reference level corresponding to input threshold shall be -15 dBm; each channel shall have +6 dB, -30 dB commandable gain control in 1 dB steps.

3.2.8 Linear PM Carrier Demodulator

The IF input shall be 70 ±0.5 MHz. The reference input level (threshold) shall be -30 dBm at an IF carrier-to-noise power ratio of 6.0 dB and a deviation of ±3.6 MHz. The demodulator shall accept up to 20 dB overdrive without degradation. Three output channels shall be provided with 50 dB isolation between worst case pairs. The output frequency response of each channel shall be ±0.5 dB from 30 Hz to 3.402 MHz with 1 percent maximum distortion. The output reference level corresponding to input threshold shall be -15 dBm; each channel shall have +6 dB, -30 dB commandable gain control in 1 dB steps.

3.2.9 Control and Monitoring

Control and monitoring interfaces shall be compatible with the control group interfaces as described in Section 3.7.

3.3 Subcarrier Modem Group

3.3.1 General Interface Characteristics

The input impedance and output impedance of all units in the group shall be 75 ohms with a return loss greater than 26 dB. The input and output reference levels for all analog circuits shall be -15 dBm. The level stability of the outputs shall be ±0.1 dB over 24 hours. The frequency stability of the modulator output subcarriers shall be 2 parts in 10^8 over 24 hours.

All digital interfaces shall conform to the levels specified in Tables XXIX (inputs) and XXX (outputs). The general timing diagram for all digital circuits is shown in Figure 4.

3.3.2 Quadriphase Subcarrier Modulator

The input shall accept a data pulse width of 200 nanoseconds (minimum) and a clock frequency of 5 MHz (maximum).

The output subcarrier frequency shall be 2.275 MHz. The modulation format shall be the four dibits (11, 10, 00, 01) cause the subcarrier reference phase to be changed 1, 3, 5, or 7 times $\pi/4$ ±1 percent radians.

All spurious and distortion products shall be less than -95 dBm in any 10 kHz from 30 Hz to 4 MHz.

3.3.3 Biphase Subcarrier Modulator

The input shall accept a data pulse width of 2 microseconds (minimum) and a clock frequency of 500 kHz (maximum).

Six subcarrier output frequencies shall be provided, selectable by command. The subcarrier frequencies and their associated maximum data

rates are shown in Table XXXI. The modulation format shall be $\pm\pi/2$ ±1 percent radians change from subcarrier reference phase for logical "1" and logical "0"; the modulation sense shall be reversible by command.

All spurious and distortion products shall be no greater than the allowable levels given in Table XXXII.

3.3.4 Linear FM Subcarrier Modulator

The input shall have commandable gain of +6 dB, -24 dB in 1 dB steps relative to the reference level. The frequency response shall be ±0.5 dB from 100 Hz to 500 kHz.

The output subcarrier frequency shall be 6.415 MHz. The maximum deviation with 1 percent linearity shall be ±500 kHz.

All spurious and distortion products shall be less than -95 dBm in any 10 kHz from 5.915 to 6.915 MHz.

TABLE XXXI. BIPHASE SUBCARRIER MODULATOR CHANNELS AND DATA RATES

Channel	Subcarrier Frequency	Data Rate, kbps
1	7.5 kHz	10
2	71 kHz	70
3	1.995 MHz	60
4	2.690 MHz	50
5	6.415 MHz	500
6	9.045 MHz	60

TABLE XXXII. BIPHASE SUBCARRIER MODULATOR OUTPUT SPECTRUM

Channel	Measurement Increment, kHz	Measurement Range	Maximum Level, dBm
1	1	30 Hz to 15 kHz	-105
2	1	18 to 124 kHz	-105
3	1	1.95 to 2.04 MHz	-105
4	1	2.653 to 2.727 MHz	-105
5	10	5.915 to 6.915 MHz	- 95
6	1	9.00 to 9.09 MHz	-105

3.3.5 Biphase Subcarrier Demodulator

The demodulator shall accept the subcarrier input frequencies and output the corresponding data rates shown in Table XXXIII. The input signal format shall be $\pm\pi/2$ radians change from subcarrier reference phase for logical "1" and logical "0"; the modulation sense shall be reversible by command.

The minimum output pulse width shall be 2 microseconds and the pulse shape and levels shall be met when terminated in 75 ohms, shunted by 100 picofarads.

The bit error rate for the reference input shall be equal to or less than 1 in 10^5. Initial bit synchronization shall be achieved within 1 second at input signal levels corresponding to a BER of 1 in 10^3. Resynchronization shall be accomplished within 1000 bit periods and shall be maintained for at least 500 bit periods after loss of signal.

3.3.6 Linear FM Subcarrier Demodulator

The subcarrier input frequency shall be 500 kHz (0.001 percent). Threshold shall occur at 10 dB below the reference input level at subcarrier to noise power ratio of 6.0 dB with a deviation of ±500 kHz. The demodulator shall accept signals of 10 dB above the reference level without degradation.

The output frequency response shall be ±0.5 dB from 30 Hz to 500 kHz with 1 percent maximum distortion at output reference level. The output level shall be commandable +6 dB, -24 dB relative to the reference level.

3.3.7 Control and Monitoring

Control and monitoring interfaces shall be compatible with the control group interface as described in Section 3.7.

TABLE XXXIII. BIPHASE SUBCARRIER DEMODULATOR CHARACTERISTICS

Subcarrier Frequency (0.001 Percent)	Data Rate, kbps
7.5 kHz	10
71 kHz	70
500 kHz	500
1.45 MHz	200
1.995 MHz	60
3.027 MHz	500

3.4 TDM Group

3.4.1 General Interface Characteristics

The input impedance and output impedance of all units in the group shall be 75 ohms with a return loss greater than 26 dB. All interfaces shall conform to the levels specified in Table XXIX (inputs) and Table XXX (outputs). The general timing diagram for all circuits is shown in Figure 4.

3.4.2 Low Rate Digital Multiplexer

The low rate multiplexer shall have two command selectable modes. Mode 1 shall accept three synchronous 19.2 kbps signals and multiplex these into a nominal 60 kbps serial output. The minimum output data pulse width in this mode shall be 16 microseconds. The multiplex format is TBD.

Mode 2 accepts one 19.2 kbps signal and a synchronous 50 kbps signal and multiplexes these into a nominal 70 kbps serial output. The minimum output data pulse width for this mode is 14 microseconds.

A clock at the output data rate is provided by the multiplexer for each mode. The output pulse shape and level shall be met when terminated in 75 ohms shunted by 100 picofarads.

3.4.3 High Rate Digital Multiplexer

The high rate multiplexer shall accept up to five synchronous input signals comprised of three 19.2 kbps signals, one 500 kbps signal, and one 5 Mbps signal.

It shall form a serial, nominal 6 Mbps data output from these inputs with a minimum data pulse width of 160 nanoseconds. The multiplex format is TBD. A 6 MHz clock shall be provided with the data output.

The output pulse shape and level shall be met when terminated in 75 ohms shunted by 50 picofarads.

3.4.4 Digital Demultiplexer

The digital demultiplexer shall have four command selectable modes with the characteristics given in Table XXXIV. The multiplex format is TBD.

Frame synchronization shall be achieved in 1000 bit periods with 0.99 probability. The output pulse shape and level shall be met when terminated in 75 ohms shunted by 100 picofarads.

3.4.5 Low Rate Channel Encoder

The low rate encoder shall accept a serial bit stream having a minimum data pulse width of 14 microseconds and a 70 kHz clock. This input

TABLE XXXIV. DIGITAL DEMULTIPLEXER MODE CHARACTERISTICS

Mode	Minimum Input Data Pulse Width, microseconds	Number of Outputs	Output Rates, kbps
1	30	2	19.2, 10
2	16	3	19.2, each
3	14	2	19.2, 50
4	4.8	4	3, 19.2 1, 140

shall be convolutionally encoded at twice the input rate with a constraint length 7 code and output a nominal 140 kbps serial data stream and 140 kHz clock.

The output pulse shape and level shall be met when terminated in 75 ohms shunted by 100 picofarads.

3.4.6 High Rate Channel Encoder

The high rate encoder shall accept a serial bit stream having a minimum data pulse width of 150 nanoseconds and a 6 MHz clock. This input shall be convolutionally encoded at twice the input rate; the code constraint length is TBD.

It shall output a serial bit stream with minimum data pulse width of 80 nanoseconds and a 12 MHz clock. The output pulse shape and level shall be met when terminated in 75 ohms shunted by 50 picofarads.

3.4.7 Channel Decoder

The channel decoder shall accept a convolutionally encoded (rate 1/2, constraint length 7) serial bit stream of minimum symbol pulse width of 16 microseconds and a 60 kHz clock. It shall output a 30 kbps data signal and a 30 kHz clock.

The bit error rate shall be 1 in 10^5 for a data bit energy to noise power spectral density ratio of 5 dB. Synchronization shall be achieved within 300 data bit periods at input signals corresponding to 1 in 10^3 BER.

3.4.8 Control and Monitoring

Control and monitoring interfaces shall be compatible with the control group interface described in Section 3.7.

3.5 Delta Modem Group

3.5.1 General Interface Characteristics

The input impedance and output impedance of all units shall be 75 ohms with a return loss greater than 26 dB. The reference level for all analog circuits shall be -15 dBm with an output level stability of ±0.1 dB over 24 hours.

All digital interfaces shall conform to the levels specified in Table XXIX (input) and Table XXX (output). The general timing diagram for all digital circuits is shown in Figure 4.

3.5.2 Delta Modulator

The delta modulator shall accept a 300 to 3400 Hz telephony input channel with inband supervisory signals. It shall sample, encode, and output a serial 19.2 kbps data stream and clock. The encoding format is TBD.

The output pulse shape and levels shall be met when terminated in 75 ohms shunted by 100 picofarads.

3.5.3 Delta Demodulator

The delta demodulator shall accept an encoded voice serial data stream with a minimum pulse width of 50 microseconds and a clock frequency of 20 kHz maximum. It shall output analog voice and telephone supervisory signals.

Harmonic distortion of an 800 Hz tone with an input BER of 1 in 10^3 shall be less than 3 percent and intermodulation products for an 800 and 2000 Hz tone mixed 4 to 1 shall be TBD.

Voice intelligibility with an input BER of 1 in 10^2 shall be better than 90 percent.

3.5.4 Digital/Analog Converter

The digital/analog converter shall accept a 7 bit, PCM encoded serial data stream with a minimum pulse width of 7 microseconds and a clock frequency of 140 kHz maximum. The encoding format is TBD.

It shall output a 30 Hz to 10 kHz analog signal with a linearity of ±1/2 LSB and less than 1 percent distortion.

3.5.5 Control and Monitoring

Control and monitoring interfaces shall be compatible with the control group interfaces as described in Section 3.7.

3.6 Baseband Switch Group

3.6.1 General Interface Characteristics

The input impedance and output impedance of all circuits shall be 75 ohms with a return loss greater than 26 dB. The input and output reference levels for the analog circuits (switches A, C, D, and F) shall be -15 dBm with an output level stability of ±0.1 dB over 24 hours.

The digital circuit interfaces shall conform to the levels specified in Table XXIX (inputs) and Table XXX (outputs). Clock and data circuits shall be switched as pairs with a maximum differential propagation delay of 10 nanoseconds. The general timing diagram for all the digital circuits is shown in Figure 4.

3.6.2 Analog Baseband Switches

Baseband switches A, C, D, and F shall provide commandable analog circuit switching. The frequency response of any through circuit shall be ±0.5 dB from 30 Hz 9.09 MHz (switches C and D) and 30 Hz to 500 kHz (switches A and F).

The crosstalk in any switch section between worst case circuit pairs shall be greater than 70 dB down from 10 dB above reference level input on the offending circuit. Output circuit quiescent noise shall be less than 0.1 mv peak to peak into 75 ohms with all other circuits unterminated.

Transient noise shall be less than 0.3 mv peak to peak into 75 ohms with all other circuits unterminated when a worst case alternate circuit is switched and less than 1 mv peak to peak when the measured circuit is switched.

3.6.3 Digital Baseband Switches

Baseband switches B and E shall provide commandable digital circuit switching. Two classes of digital circuits shall be switched; high rate and low rate. The high rate circuits shall have a minimum data pulse width of 200 nanoseconds and a maximum clock frequency of 5 MHz. The low rate circuits shall have a minimum data pulse width of 2 microseconds and a maximum clock frequency of 500 kHz.

The output pulse shape and levels shall be met when terminated in 75 ohms shunted by 100 picofarads (low rate circuits) or 50 picofarads (high rate circuits).

All crosstalk and switching transients shall not exceed ±0.4 volt into 75 ohms and shall not cause the data or clock timing to vary more than ±5 nanoseconds.

3.6.4 Control and Monitoring

Control and monitoring interfaces shall be compatible with the control group interface described in Section 3.7.

3.7 Control Group

3.7.1 General Interface Characteristics

The input impedance and the output impedance of all units in this group shall be 75 ohms with a return loss greater than 26 dB.

All digital interfaces shall conform to the level specified in Table XXIX (inputs) and Table XXX (outputs). The general timing diagram for all digital circuits is shown in Figure 4.

3.7.2 Remote Multiplexer/Demultiplexer

Each remote multiplexer/demultiplexer shall provide up to 32 pulse outputs and up to 32 serial digital outputs and clock. The serial digital outputs are 8 bit words. The minimum pulse width of the discrete pulse is TBD. The minimum pulse width and the clock frequency of the serial digital output is TBD.

Each remote multiplexer/demultiplexer shall accept up to 32, parallel analog inputs of 0 to +5 volts peak to peak and up to 256 bilevel discrete data inputs. The dc stability and frequency response of the analog inputs are TBD. The minimum pulse width of the discrete data input is TBD.

The analog inputs shall be detected differentially across a two-wire, balanced interface. The input isolation from either signal line to signal return, power return, or any other input or output line shall be greater than 70 dB. The common mode rejection between input line pairs shall be greater than 90 dB.

3.7.3 Reference Frequency Bus

Two reference frequency carriers shall be provided at each output terminal. The carrier frequencies shall be TBD MHz. The frequency stability of the carriers shall be 2 parts in 10^8 over 24 hours. The phase stability shall be TBD.

Each output shall be isolated so that a reference level input signal applied to any output terminal shall be no greater than -75 dBm at any other output terminal. The reference carrier level at any output shall not change more than ±0.1 dB, when any other output is open or short circuited nor should the reference carrier phase change more than TBD degrees under the same conditions.

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4.0 INTERNAL COMMUNICATION ASSEMBLY FUNCTIONAL CHARACTERISTICS

4.1 Audio-Video Bus Group

The audio-video bus group consists primarily of the audio-video bus and modems required to provide access to the medium rate and video bus channels. Figure 5 shows the interconnection of this group with the other internal communication assembly groups. A functional description of each equipment type follows.

4.1.1 Audio-Video Bus

The audio-video bus carries 12 4.5 MHz video channels and 10 48 kHz medium rate channels to all areas of the space station. It interconnects these channels to various ICA equipments using audio-video units. In addition to the video and medium rate channels, the bus carries an orderwire which contains the video sync reference signal, AVU command channels, and appropriate channel reference frequencies. Two redundant buses are provided.

4.1.2 Audio-Video Units

Audio-video units (AVU) are modems that provide access to the video and medium rate bus channels. Each AVU connects one duplex medium rate circuit, and two simplex, video circuits to corresponding bus channels. One simplex video circuit provides for reception of selected video channels, the other provides for transmission of video information onto an assigned video channel. Several AVUs may be paralleled to provide any equipment access to more bus channels than a single AVU can provide.

Each AVU conditions all signals that it inserts onto the bus as may be required by the bus transmission characteristics. The receiving AVU removes the signal conditioning.

Each AVU removes the video sync reference signal from the bus orderwire and connects it to an output terminal. The video communication group uses this signal to synchronize all television video sources with the video sync reference generator.

All AVUs remove the channel reference frequencies from the bus orderwire. Each AVU uses these frequency references to synthesize the carrier frequencies needed to gain access to all audio-video bus channels.

All AVUs operate under direct control of the ICA control group via the bus orderwire. Control group commands assign each AVU a duplex medium rate channel, a set of receive-only video channels, and one transmit-only video channel. Each AVU provides access to its assigned medium rate bus channel. This channel assignment normally remains fixed, but can be changed upon command.

Each AVU has a manually operated receive-only channel selection switch that allows station personnel to switch that AVU to any one of a set of assigned receive-only video channels. Since AVU receive-only channel assignments are controlled, other video channels may be reserved for private use.

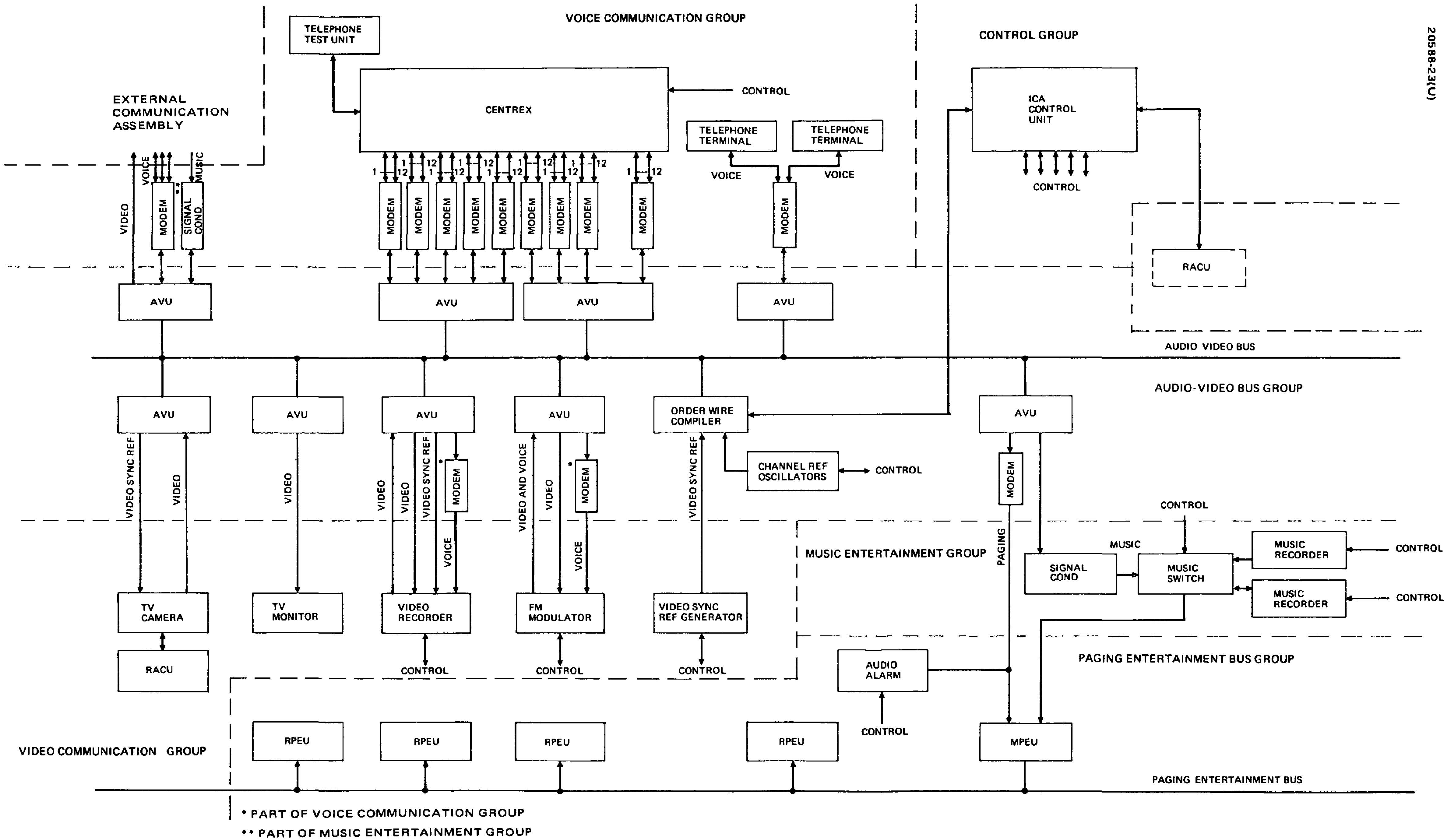
Video transmit-only channel assignments are normally not made until a request for such an assignment is received from the DPA. The control group assigns the specified AVU access to an available bus video channel.

4.1.3 Orderwire Compiler

The orderwire compiler assembles the AVU commands received from the ICA control unit, the video sync reference signal from the video sync reference generator and appropriate channel reference frequencies, conditions those signals and places them on the audio-video bus for transmission to all AVUs.

4.1.4 Control and Monitoring

The specific control commands required for audio-video bus group operation are listed in Table XXXV. The group receives the specific commands from the ICA control group and distributes them to the addressed equipment using the audio-video bus orderwire. Certain parameters may be monitored that provide a reliable index to bus operability. These parameters are listed in Table XXXVI.



• PART OF VOICE COMMUNICATION GROUP
•• PART OF MUSIC ENTERTAINMENT GROUP

Figure 5. Internal Communication Assembly Block Diagram

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TABLE XXXV. AUDIO-VIDEO BUS GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1	Pulse	Audio-video bus 1 Off
2	Pulse	Audio-video bus 1 On
3	Pulse	Audio-video bus 2 Off
4	Pulse	Audio-video bus 2 On
5	Pulse	Bus frequency reference generator 1 Off
6	Pulse	Bus frequency reference generator 1 On
7	Pulse	Bus frequency reference generator 2 Off
8	Pulse	Bus frequency reference generator 2 On
9	Serial	AVU medium rate channel assignment
10	Serial	AVU video receive channel assignment
11	Serial	AVU video transmit channel assignment
8	Pulse	Total
3	Serial	

TABLE XXXVI. AUDIO-VIDEO BUS GROUP MONITORED PARAMETERS

Parameter Number	Parameter Type	Parameter Monitored
1	Analog	Audio-video bus channel reference frequency amplitudes
2	Analog	Audio-video bus medium rate channel signal power
3	Analog	Audio-video bus video channel signal power
4	Analog	AVU frequency synthesizer output amplitude
5	Bilevel	Audio-video bus 1 On/Off
6	Bilevel	Audio-video bus 2 On/Off
7	Bilevel	Bus reference frequency generator 1 On/Off
8	Bilevel	Bus reference frequency generator 2 On/Off
4	Analog	Total
4	Bilevel	

4.2 Voice Communication Group

The voice communication group consists principally of the telephone equipments and voice recorders. Figure 5 shows the interconnection of the various equipments of this group. An operational description of each equipment type follows.

4.2.1 Telephone Equipment

The telephone equipment consists of those units necessary to provide the onboard telephone communication function via audio-video bus circuits. It includes telephone sets, modem units, and a central telephone switchboard (CENTREX) located in the station module communication racks.

4.2.1.1 Modem Units

Modem units separate a single, duplex nominal 48 kHz circuit into 12 duplex nominal 4 kHz telephone circuits. The 4 kHz circuits connect to telephone sets or telephone data sets to provide either voice or low rate data access to the bus. Each modem unit connects to an AVU for access to a 48 kHz bus channel. The modem unit also appropriately conditions voice or data input/output signals.

4.2.1.2 Telephone Sets

The telephone sets are functionally identical to the standard telephone set widely used in conventional telephone systems. Each telephone set connects to a modem unit using a duplex nominal 4 kHz circuit. Each terminal is connected to the central switchboard via a dedicated circuit. The circuit assignments may be changed manually at the modem unit by connecting to another of the 12 channels and remotely instructing the AVU to select another medium rate channel.

4.2.1.3 Central Telephone Switchboard

The central telephone switchboard operates in a manner functionally similar to the central switchboard of conventional telephone systems. It provides the circuit switching, supervisory control and signalling, and call monitoring functions required to provide direct dial service between telephone sets on the MSS and access to ground toll trunks through external RF links.

The switchboard provides private or conference call service. Addresses of called parties are normally received from the originating terminal as in conventional telephone systems. However, the CENTREX may also receive commands from the ICA control group to interconnect selected telephone sets or to operate supervisory signalling functions. Such commands consist of instructions to interconnect specified CENTREX inputs and outputs and to operate specific supervisory signalling units.

To allow maximum CENTREX flexibility, the telephone addresses associated with CENTREX output lines may be reprogrammed remotely by the DPA. Should an output line become inoperative due to a CENTREX switch element failure, the telephone address assigned to that line may be moved to another.

The ECA voice links terminate at a modem on an equal number of 4 kHz telephone circuits. A CENTREX interconnects these circuits with any other telephone circuit in the same manner as it does a circuit connected to a telephone terminal. All incoming calls on the voice links are preceded by supervisory signals that inform the switchboard of the address of the called party. Similarly, all outgoing calls are also preceded by supervisory signals to allow call routing to the call destination.

The paging channel of the paging-entertainment bus, the voice recorder, and the voice channel of the video recorder are also accessed through the CENTREX. Each is terminated on the switchboard with an address so that it may be accessed by any telephone set.

4.2.1.4 Voice Recorders

Voice recorders provide the capability to record from any telephone circuit. They may be called directly or included as a party in a conference call. Calling a recorder activates the tape transport mechanism and places the recorder in the record mode. Each recorder contains automatic gain control circuitry to adjust both record and playback levels to accommodate the range of input signal levels and variations in tape recording level.

4.2.1.5 Hardwire Intercom

The hardwire intercom is a hardwire line running to all nonhabitable as well as habitable space station areas. The line is used during station buildup to transmit voice powered audio signals from one area of the station to another. Following station buildup, need for the hardwire intercom terminates and the line is used for the paging and entertainment bus.

4.2.2 Control and Monitoring

The voice communication group normally operates with a minimum of external control. Supervisory signals similar in function to those of conventional telephone systems provide the means by which the CENTREX interconnects the telephone sets and operates the telephone equipments.

In addition, the voice communication group requires external control to select particular equipments where redundant units are available, to generate the commands needed to place those equipments in operation, and to monitor equipment performance. The control commands required to operate the voice communication group equipments are listed in Table XXXVII.

The ICA control group may monitor any parameters as may be determined that will serve as a good index to equipment operability. An estimate of monitored parameters is given in Table XXXVIII.

TABLE XXXVII. VOICE COMMUNICATION GROUP CONTROL COMMAND

Command Number	Command Number	Function Controlled
1	Pulse	CENTREX 1 Off
2	Pulse	CENTREX 1 On
3-4	Pulse	CENTREX 2 Off/On
5-6	Pulse	Test unit On/Off
7	Serial	CENTREX address programming command
8	Serial	CENTREX switching command
9	Serial	Supervisory signal unit mode select command
6 3	Pulse Serial	Total

TABLE XXXVIII. VOICE COMMUNICATION GROUP MONITORED PARAMETERS

Parameter Number	Parameter Type	Parameter Monitored
1-2	Bilevel	CENTREX 1 On/Off
3-4	Bilevel	CENTREX 2 On/Off
5-6	Bilevel	Test unit On/Off
6	Bilevel	Total

4.3 Video Communication Group

The video communication group consists principally of the TV cameras, TV monitors, and TV recorders used for CCTV operation aboard the MSS. Additionally, it includes other equipments necessary for CCTV operations, such as a master sync generator and built-in test equipments. Figure 5 is a block diagram of the video communication group. A functional description of each equipment type follows.

4.3.1 TV Camera

Television cameras provide the capability to monitor station and experiment operations. Typically, they may be mounted externally to the space station to monitor docking and undocking operations or internally to monitor experiments and space station equipments. Each operating camera is connected to a video channel and to the video sync reference channel of the audio-video bus via an AVU. Contained on the sync reference channel are the color reference carrier and horizontal and vertical timing signals that originate in the master sync generator. The cameras utilize these timing and reference signals to generate the horizontal and vertical drive, horizontal and vertical sync, horizontal and vertical blanking, chrominance subcarrier, and color burst flag needed to operate the camera, and to provide the NTSC standard composite video signal at the camera output. The AVU inserts the video signal onto a bus video channel previously assigned by the ICA control group.

Cameras located in areas not normally accessible to crew members must be capable of being remotely adjusted and positioned. Accordingly, each camera connects to a RACU to receive the commands needed to perform these functions and to provide DPA access to built-in camera self-test circuits and monitoring points.

4.3.2 TV Monitors

Television monitors are located in such MSS areas as the operations and experiment control centers, the commander's staterooms, and crew lounges and dining areas. Each TV monitor connects to the audio-video bus via an AVU. A channel selection switch located on each AVU allows station personnel to select any one of the video channels which that AVU is programmed to receive. Certain video channels may be reserved for viewing exclusively at predetermined locations by programming AVUs at those locations to receive that set of channels.

The TV monitors also are used for crew entertainment. Prerecorded TV programming is inserted onto an audio-video bus channel from a video recorder. Those monitors having AVUs with programmed capability of receiving entertainment channels can receive the entertainment program.

4.3.3 Video Recorders

Video recorders provide the capability to record video signals present on any of the audio-video bus video channels. Requests to record particular channels originate in the DPA. The ICA control group selects an available recorder and connects it to the selected bus video channel.

The video recorders are also used to play back prerecorded tape cassettes. In this mode of operation, the ICA control group is notified by the DPA of the recorder selected for playback. The ICA control group selects an unused video channel of the audio-video bus and generates the necessary instructions to the video recorder, and to the audio-video bus group to initiate playback and route the signal onto the selected audio-video bus channel. During playback, the video recorder uses video sync reference signals from the bus orderwire to synchronize the playback video sync generator.

Except for recorder mode selection control, recorder operation is assumed to be manual. Station personnel load and index tapes, and set up the recorder to prepare it for operation. Any automated functions in addition to mode selection require commands directly from the DPA via a RACU interface at each recorder.

4.3.4 Video Sync Reference Generator

The video sync reference generator provides the reference signals necessary to proper operation of the TV recorders and remote TV cameras. It contains a color reference subcarrier oscillator from which it derives vertical and horizontal sweep timing signals. These signals are modulated onto the color reference carrier and placed in the audio-video bus orderwire for distribution to each remote camera and recorder. The remote cameras use this signal to construct the necessary sync and drive signals needed to operate the camera and furnish NTSC composite video at the camera output. All cameras are synchronized to a common reference signal so that picture stability is not lost when switching between video sources.

The video sync generator also furnishes sweep timing signals to each video recorder. During playback, the video recorder uses these timing signals to lock the playback video signal in sync with the video sync reference generator.

4.3.5 FM Modulator

The FM modulator receives a voice signal input from one of the telephone channels, frequency-modulates that signal on a carrier of proper frequency, and inserts that signal on a selected video channel of the audio-video bus. The resultant video signal on that channel then consists of NTSC standard composite video plus an FM modulated voice signal forming an NTSC standard composite television signal. This signal may then be distributed to monitors throughout the space station or to the external communication assembly for transmission to ground. The FM modulator monitors the amplitude of the color reference burst to adjust the FM carrier power for the proper power relationship between video and aural subcarriers. The FM carrier is then used as the reference level for the combined video signal by the ECA modulators.

4.3.6 Control and Monitoring

The group receives control commands as listed in Table XXXIX from the ICA control group to operate the group equipments.

Station personnel perform most of the testing of the video communication group. They test the TV recorders, TV cameras, and TV monitors by observing output signals on a monitor or by utilizing the special test signals as applicable to each unit.

TABLE XXXIX. VIDEO COMMUNICATION GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1	Pulse	Video recorder 1 On
2	Pulse	Video recorder 1 Off
3-4	Pulse	Video recorder 2 On/Off
5-6	Pulse	Video recorder 3 On/Off
7-8	Pulse	Video recorder 4 On/Off
9-10	Pulse	Video sync reference generator 1 On/Off
11-12	Pulse	Video sync reference generator 2 On/Off
13-14	Pulse	FM modulator 1 On/Off
15-16	Pulse	FM modulator 2 On/Off
17	Serial	Video recorder 1 mode select
18	Serial	Video recorder 2 mode select
19	Serial	Video recorder 3 mode select
16	Pulse	Total
3	Serial	

Certain group equipments such as the video sync reference unit are critical to the operation of the video communication group. Important parameters from these units are continuously monitored to detect unit failure. The self-test parameters presently identified are listed in Table XL.

TABLE XL. VIDEO COMMUNICATION GROUP MONITORED PARAMETERS

Parameter Number	Parameter Type	Parameters Monitored
1	Analog	Video sync reference signal amplitude
2-3	Bilevel	Video recorder 1 On/Off
3-4	Bilevel	Video recorder 2 On/Off
5-6	Bilevel	Video recorder 3 On/Off
7-8	Bilevel	Video recorder 4 On/Off
9-10	Bilevel	Video sync reference generator 1 On/Off
11-12	Bilevel	Video sync reference generator 2 On/Off
13-14	Bilevel	FM Modulator 1 On/Off
14-15	Bilevel	FM modulator 2 On/Off
1 14	Analog Bilevel	Total

4.4 Music Entertainment Group

The music entertainment group consists of the music switch, signal conditioning units, and music recorders. Figure 5 shows the interconnection of the various equipments of this group. A functional description of each equipment type follows.

4.4.1 Music Switch Unit

The music switch unit is a three-by-three switch matrix that receives and connects each of three input circuits to one of three output circuits. Each of the circuits carries 10 kHz music signals that either originate at one of the two music recorders or are received from the external communication assembly. The three 10 kHz output circuits terminate on three paging-entertainment bus inputs.

4.4.2 Signal Conditioning Units

Signal conditioning units properly condition the 10 kHz music signal for connection to a 48 kHz AVU circuit. A conditioning unit is required to condition the ECA 10 kHz music signal for transmission over the audio-video bus to the music entertainment group. Another conditioning unit is located following

the AVU that removes the signal from the bus to remove the conditioning placed in the signal by the first unit.

4.4.3 Music Recorders

The music recorders provide the capability to record the 10 kHz ECA music channel and to play back prerecorded music cartridges. With the exception of recorder mode control, all recorder control is assumed to be manual. Station personnel load and unload the tape cartridges and index tapes.

4.4.4 Control and Monitoring

The control commands for the music entertainment group are listed in Table XLI.

TABLE XLI. MUSIC ENTERTAINMENT GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1	Pulse	Music switch 1 On
2	Pulse	Music switch 1 Off
3-4	Pulse	Music switch 2 On/Off
5-6	Pulse	Music recorder 1 On/Off
7-8	Pulse	Music recorder 2 On/Off
9-10	Pulse	Music recorder 3 On/Off
10-11	Pulse	Music recorder 4 On/Off
12	Serial	Music switch 1 configuration command
13	Serial	Music switch 2 configuration command
14	Serial	Music recorder 1 mode select command
15	Serial	Music recorder 2 mode select command
16	Serial	Music recorder 3 mode select command
17	Serial	Music recorder 4 mode select command
11	Pulse	Total
6	Serial	

Due to the simplicity and inherent reliability of music entertainment group equipments and to the noncritical nature of their function, no provision is made for any automated self-test functions in this group. The group may be tested by station personnel using operational signals. The parameters monitored are listed in Table XLII.

The group interconnects with the ICA control group using the control interface described in Section 2.8.3. Should the need for self-test functions arise, the same control interface circuit used for group control may be used for group self-test as in other ICA groups.

TABLE XLII. MUSIC ENTERTAINMENT GROUP MONITORED PARAMETERS

Parameter Number	Parameter Type	Parameter Monitored
1-2	Bilevel	Music switch 1 On/Off
3-4	Bilevel	Music switch 2 On/Off
5-12	Bilevel	Music recorders On/Off
12	Bilevel	Total

4.5 Paging and Entertainment Bus Group

The paging and entertainment bus group provides for distribution of paging, alarm, and music entertainment to all habitable MSS areas. It is composed of the paging and entertainment bus, master P-E units, and remote P-E units. A functional description of each equipment type follows.

4.5.1 Paging-Entertainment Bus

The paging-entertainment bus is a simple hardwire line that carries one paging channel and six music channels to all space station areas. During the early phases of station buildup, this line serves as the hardwire intercom. Following buildup, it is used exclusively for paging and entertainment signals. Two redundant buses are provided.

4.5.2 Master Paging-Entertainment Unit

The master paging-entertainment unit (MPEU) is a multiplexer to insert the paging channel and three music channels onto the paging and entertainment bus. It receives paging channel inputs from the telephone switchboard and music channel inputs from the music switch. The ICA control group selects the P-E bus channels on which music inputs are placed.

The MPEU also contains a channel reference oscillator that supplies a channel reference frequency to all RPEUs. Each RPEU uses the channel reference frequency to demultiplex any one of the P-E bus music channels.

4.5.3 Remote Paging-Entertainment Unit

The RPEU is a demultiplexer used to remove the paging channel and any one of the music channels from the paging and entertainment bus.

Since the paging channel is used for both paging and audio alarm, it is continuously monitored by all RPEUs. Any signals received on this channel are routed to the loudspeaker bypassing any volume control and disabling reception of any music channel.

The RPEU has a channel selection switch that allows any of the paging and entertainment bus music channels to be selected. The selected channel is routed through a volume control to the loudspeaker.

Depending on paging and entertainment bus design, the RPEU may also require channel equalization amplifiers to compensate received signals for any undesired channel transmission characteristics.

4.5.4 Audio Alarm

The audio alarm function is contained within the paging and entertainment bus group. Alarm activation commands are sent from the DPA to the ICA control group. The control group responds by activating the audio alarm and inserting it onto the paging channel of the paging and entertainment bus. Each RPEU receives the audio alarm and routes it to a local speaker bypassing any local volume control and disabling music reception.

4.5.5 Control and Monitoring

The control commands identified with the paging and entertainment bus group are listed in Table XLIII.

The paging and entertainment group is tested mainly by station personnel. The personnel use either operational signals or test signals to check the operability and relative quality of each bus channel, and bus equipment. Certain parameters that provide a good index to bus operability are monitored. These are listed in Table XLIV.

TABLE XLIII. PAGING AND ENTERTAINMENT BUS GROUP CONTROL COMMANDS

Command Number	Command Type	Function Controlled
1	Pulse	P-E bus 1 On
2	Pulse	P-E bus 1 Off
3-4	Pulse	P-E bus 2 On/Off
5-6	Pulse	Bus reference frequency oscillator 1 On/Off
7-8	Pulse	Bus reference frequency oscillator 2 On/Off
9-10	Pulse	Audio alarm unit 1 On/Off
11-12	Pulse	Audio alarm unit 2 On/Off
13	Serial	Input line 1 bus channel assignment
14	Serial	Input line 2 bus channel assignment
15	Serial	Input line 3 bus channel assignment
16	Serial	Input line 4 bus channel assignment
17	Serial	Input line 5 bus channel assignment
18	Serial	Input line 6 bus channel assignment
12 6	Pulse Serial	Total

TABLE XLIV. PAGING AND ENTERTAINMENT BUS GROUP MONITORED PARAMETERS

Parameter Number	Parameter Type	Parameter Monitored
1	Analog	MPEU 1 channel reference oscillator output amplitude
2	Analog	MPEU 2 channel reference oscillator output amplitude

TABLE XLIV (continued)

Parameter Number	Parameter Type	ICA Group
3	Analog	MPEU 1 frequency synthesizer output amplitude
4	Analog	MPEU 2 channel reference oscillator amplitude
5-6	Bilevel	Bus reference frequency oscillator 1 On/Off
7-8	Bilevel	Bus reference frequency oscillator 2 On/Off
9-10	Bilevel	Audio alarm unit 1 On/Off
11-12	Bilevel	Audio alarm unit 2 On/Off
4	Analog	Total
8	Bilevel	

4.6 Control Group

The control group provides monitoring and control of the entire internal communication assembly. A control group is provided for each ICA in both SM-1 and SM-4. Either of these ICA control groups may be selected by the DPA to operate both ICA groups. The unit selected then functions as a master ICA control group; the other group operates as a slave to the master providing the master with access to and control of ICA equipments located in its communication rack. The master and slave ICA control groups communicate with each other using the RACU communication mode of the digital data bus.

4.6.1 Control Group Functions

The ICA control group functions are identical to those described in the ECA control group (Section 2.8).

4.6.2 ICA Control and Monitoring

The control commands identified as being sent from the ICA control group to each ICA group have been identified in the preceding sections. Table XLV summarizes the ICA control commands.

The control group monitors appropriate parameters in all ICA groups. These parameters have been identified in the discussions on each particular group. Table XLVI summarizes these monitoring requirements.

TABLE XLV. SUMMARY OF ICA CONTROL COMMANDS

Command Number	Command Type	ICA Group
8 3	Pulse Serial	Audio-video bus
6 5	Pulse Serial	Voice communication
16 3	Pulse Serial	Video communication
11 6	Pulse Serial	Music entertainment
12 6	Pulse Serial	Paging entertainment
44 12	Pulse Serial	Control
97 35	Pulse Serial	Total

TABLE XLVI. SUMMARY OF ICA MONITORED PARAMETERS

Parameter Number	Parameter Type	ICA Group
4 4	Analog Bilevel	Audio-video bus
0 6	Analog Bilevel	Voice communication
1 14	Analog Bilevel	Video communication
0 12	Analog Bilevel	Music entertainment
4 8	Analog Bilevel	Paging entertainment
40 36	Analog Bilevel	Control
49 80	Analog Bilevel	Total

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5.0 INTERNAL COMMUNICATION ASSEMBLY ELECTRICAL INTERFACE CHARACTERISTICS

5.1 General Interface Characteristics

The interfaces between groups within the ICA, with the exception of the audio-video bus group, are designed to consist of standard telephone, 10 kHz audio, and TV video circuits. These circuits will not be defined here; industrial standards of the telephone industry, commercial audio/entertainment equipment designs, and TV studio and transmission practices, respectively, should be applied.

5.2 Audio-Video Bus Group

5.2.1 Video Circuit

A full duplex NTSC video circuit shall be provided at each audio-video unit interface. The input impedance and the output impedance shall be 75 ohms with a return loss greater than 26 dB. The input and output reference levels shall be 1 volt peak to peak with an output level stability of ±0.1 dB over 24 hours.

The frequency response at the terminals shall be ±0.5 dB from 30 Hz to 4.5 MHz; CCIR preemphasis and deemphasis shall be used for bus transmission.

The one-way differential phase change shall be no greater than 0.2 degree and the differential gain no greater than 1 percent as measured from 10 to 90 percent average picture level.

The one-way peak-to-peak video to weighted rms noise power ratio at the output reference level shall be greater than 63 dB.

The circuit shall accept up to 6 dB overdrive without degradation. A commandable gain control shall be provided to adjust the output +6 dB, -24 dB in 1 dB steps.

5.2.2 Medium Rate Circuit

A full duplex medium rate circuit shall be provided at each audio-video unit interface suitable for transmission of a standard telephony voice channel group. The input impedance and the output impedance shall be 75 ohms with a return loss greater than 26 dB. The input and output reference levels shall be -15 dBm with an output level stability of 0.1 dB over 24 hours.

The frequency response at the terminals shall be ±0.25 dB from 300 Hz to 40.8 kHz. Equalization for bus transmission characteristics shall be provided as required. The frequency translation error shall be no greater than 100 Hz.

The one-way attenuation distortion and envelope delay distortion over the passband shall be no greater than ±4 dB and 2.5 microseconds, respectively, at the reference level output.

The one-way rms signal to rms noise power ratio shall be greater than 40 dB at the output reference level. Spurious intermodulation and distortion products shall not exceed -75 dBm in 1 kHz from 300 Hz to 40.8 kHz.

The circuit shall accept up to 6 dB overdrive without degradation. A commandable gain control shall be provided to adjust the output +6 dB, -24 dB in 1 dB steps.

5.3 Control and Monitoring

Control and monitoring interfaces in the ICA shall be compatible with the ECA control group interfaces described in Section 3.7.